SURVEY OF HEAVY-DUTY DIESEL ENGINE REBUILDING, RECONDITIONING, AND REMANUFACTURING PRACTICES

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ABSTRACT

A survey was conducted to determine the emissions impact of rebuilt, reconditioned and remanufactured heavy-duty diesel engines sold in California. Proper rebuilding practices generally return engines to as new condition, that is they will emit at levels close to those of new engines. Therefore, information was collected from fleet maintenance shops, independent rebuild shops and diesel injection repair specialists on the frequency of <u>improper rebuilding practices</u> observed in the field. Data was also collected from manufacturers and regulatory agencies on the emissions impact of improper rebuilding practices.

An analysis of the data collected indicates that improper rebuilding practices <u>can</u> have a significant impact on emission levels: 25 percent for hydrocarbons (HC) and 3.1 percent for oxides of nitrogen (NOx). Stated another way, improper rebuilding practices <u>can</u> increase heavy-duty diesel emissions of HC by 11.86 tons per day and NOx by 11.42 tons per day in 1986. These increases represent an overall increase in total vehicular emissions of 0.9 percent for HC and 0.7 percent for NOx.

Two general categories of improper rebuilding practices were identified: improper equipment replacement; and improper equipment calibration. Improper or incorrect equipment replacement is most likely to occur during a rebuild and is estimated to account for approximately 20 percent of the increase in HC emissions and 33 percent of the increase in NOx emissions identified above. Improper equipment calibration can occur either in the course of a rebuild or during normal maintenance activities in the field. It is not possible to quantitatively allocate the observed rate of improper calibration between normal maintenance and rebuild from the data collected in the survey. However, conversations with fleet and dealer rebuild shops and equipment repair facilities indicate that warranty concerns make improper calibrations financially unattractive. Therefore, it is

estimated that roughly 80 percent of the 11.86 tons per day increase in HC is not due to rebuilding, but due to improper field maintenance practices. Similarly it is estimated that roughly 67 percent of the 11.42 tons per day increase in NOx is due to improper field repair practices.

The primary conclusion of the study is that improper rebuilding practices are not estimated to have a significant impact on emissions.

Survey of Heavy-Duty Diesel
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1. SUMMARY AND CONCLUSIONS

Emissions from heavy-duty diesel-powered vehicles (HDDV's) are an important contributor to violations of health-based ambient air quality standards for nitrogen dioxide and inhalable particles in California. There are several reasons for the relatively high emissions contributions of these vehicles:

- the emission standards in force today for HDDV's are substantially less stringent than those for light duty vehicles;
- the long lifespan of HDDV's diminishes the effectiveness of new vehicle emission standards because the older, higher emitting vehicles stay in operation for many years;
- California's industrial firms and its ports are a terminus for many national trucking firms that operate higher polluting HDDV's certified to federal emission standards on California highways.

Most heavy-duty diesel engines are designed to allow the easy replacement of components subjected to high wear so that the engine retains a long useful life. The replacement of these high wear parts is generally described as a rebuild.

There is concern that California engines are being rebuilt to federal specifications or that changes in components, for either cost or performance motivations, are increasing the emission levels above their original certification levels. The purpose of this study was to determine whether HDDV rebuilding practices are a significant source of excess emissions.

To gain a better understanding of the rebuild, reconditioning and remanufacturing industry, the following tasks were performed:

1. Determine, through conversations with engine manufacturers and engineering judgment, the emission critical parts replaced during a rebuild.

2. Identify segments of the rebuilding industry for a questionnaire survey and assemble mailing lists for them.

3. Establish contacts with the technical representatives of the major engine manufacturers to collect data and their insights on industry practice and design issues.

4. Design and test questionnaires that solicit relevant information from each industry segment.

5. Execute the surveys, supported with telephone interviews and site surveys to collect the necessary information.

6. Computerize the responses and analyze the data for significant trends.

7. Conduct follow-up conversations with questionnaire respondents to resolve inconsistencies.

8. Integrate the results of the analysis to determine the rates of incorrect component replacement and rebuild to federal specifications.

9. Conduct site visits to gain a practical appreciation of the work involved and to determine whether the correct parts are in fact being replaced on California engines.

10. Using data on the emissions impact of incorrect rebuild practices and estimates of the rate of occurrence of incorrect rebuilds, estimate the aggregate impact of the rebuilding industry on California HDDV's emissions.

11. Prepare a report summarizing the work performed, estimating the emissions impact of the rebuilding industry, and drawing conclusions on the rate of incorrect rebuilds occurring in the field.

1.1 SUMMARY OF SURVEY RESULTS AND DATA ANALYSIS

Overview

The nomenclature used to describe the range of possible repairs to heavy duty diesel engines is not exact and frequently some of the terms are used interchangeably. A summary of the primary repair processes is presented below.

Rebuilding - covers a broad range of repairs that can occur over the useful life of the engine. These repairs range from the replacement of broken parts to a thorough disassembly, inspection and replacement of parts based on the number of miles or hours of service that an engine has experienced and the procedures recommended by manufacturers for engines with that level of service. Generally, rebuilding is divided into two categories - in-frame and out-of-frame. The in-frame occurs with the engine in the vehicle which consequently limits the range of inspections and repairs. Normally, this type of rebuild occurs early in an engine life. The out-of-frame requires that the engine be removed from the truck and placed on a stand. The range of inspections and repairs possible in this process is far more extensive than with an in-frame rebuild. This type of rebuild occurs later in an engine's life when more extensive repairs are required.

Reconditioning - generally covers the range of repairs that occur in the rebuilding process.

Remanufacturing - at the end of its useful economic life (additional rebuilds are no longer cost effective), an engine is sent to a manufacturing facility and <u>all</u> parts are stripped from the block. These parts are segregated according to function, cleaned, inspected and either repaired or scrapped. Subassemblies (e.g., turbo changes, fuel injection pumps, oil pumps, etc.) are also torn down to their component parts and follow the same process. The block is then rebuilt with either new or reconditioned equipment. The engine that emerges from this process is unlikely to have any of the parts that it entered into the factory with, they have either been discarded or incorporated into a different engine after repair.

Data collected from engine manufacturers, the predominant force in the remanufacturing industry, indicated that less than 5 percent of the engine sales occurring in California in 1984 and 1985 were remanufactured. The remanufactured engines are required to achieve the same emission certification levels that they met when they were new. Insufficient data were available to estimate the number of rebuilds conducted on California certified engines in each of the recent calendar years.

<u>Rebuild Frequency and Useful Life</u>

From a regulatory perspective, one of the most important questions related to HDDV's is how long, on average, do they last, and what is their useful life? Data on the number of miles an average heavy-duty engine travels before it is too worn to repair, and the average number of rebuilds it will receive, were collected from rebuild shops across the country. On the basis of approximately 40 responses to this question, we found that an average engine receives 4 rebuilds and travels slightly more than 1 million miles in its lifetime.

Rebuild Costs

A large body of data was collected on the cost of rebuilds from every group surveyed in this study. Results were compared from three viewpoints: fleets; rebuild shops; and manufacturers. Generally, the responses were consistent: the cost of an in-frame rebuild is substantially less than the cost of an out-of-frame for medium-heavy and heavy-heavy duty diesel engines. In all cases, the cost of rebuild was substantially less than the cost of a new engine. The average cost of an in-frame rebuild of a heavy-duty diesel engine is estimated to be approximately 40 percent of the cost of a new engine. The cost of an out-of-frame rebuild is estimated to be approximately 65 percent of the cost of a new engine.

Discussions with engine remanufacturers indicated that the cost of their engines was typically in the range of 65 to 70 percent of new engine prices. Given the more extensive cleaning, inspection and replacement procedures followed in the remanufacturing process, the higher cost is not unexpected. The economies of scale with these operations, however, dampen the cost increment above the rebuilding process.

Data on the mileage accumulated between rebuilds were also collected. It shows that the rebuilds are cost effective, because the increase in engine life from a rebuild is very high. The increased mileage that comes from the first in-frame rebuild for a heavy-duty engine is estimated to be approximately 300,000 miles.

Aftermarket Parts

Little information is available on the quality of original equipment manufacturer (OEM) versus aftermarket part quality, and no information on their emission performance is available. Nevertheless, concern has been expressed that aftermarket parts are of inferior quality, are low priced, and that use of these parts leads to emission increases.

Based on information collected in this study, it appears that aftermarket part usage is not extensive - an upper limit of 15 percent was identified. According to conversations with four aftermarket suppliers, the production specifications for aftermarket parts are the same as those set by the engine manufacturers. Many of the parts manufacturers supply the same part to the aftermarket that they supply to the OEM.

Conversations with OEM's indicated that they believe the problem with aftermarket parts is one of durability, not emissions. They also indicated that some types of non-OEM parts, such as the injector or the turbocharger, may not incorporate all of the design changes for a specific engine, or that they might not distinguish between federal and California ratings. In conversations with aftermarket parts suppliers, we could find no evidence to support these assertions.

The prices charged for emission critical aftermarket parts are not consistently lower than those charged by OEM dealers. In fact, the price relationship between them varies, with several cases noted where aftermarket parts were either equal or higher in price than OEM parts.

Frequency of Uprating

Uprating refers to the practice of rebuilding an older engine to a newer specification, usually to increase the horsepower and/or its efficiency. An engine can usually be uprated in any of the three rebuild modes. However, some equipment changes may preclude an in-frame rebuild from uprating selected engines. Data on this subject were collected in all of the rebuild surveys. Estimates of uprating varied between fleets and rebuild shops. The fleet average estimate was 41 percent and the rebuild shop average 23 percent, with very large variations in these responses. Manufacturers estimated the activity at a lower level of 10 to 20 percent.

From an emissions perspective, uprating presents two options:

- change the engine specifications from a California to a 49-state engine and increase its emissions; or

- uprate a California engine to a new California specification and decrease its emissions.

Because of the performance advantage of a federally certified engine, in terms of both fuel economy and acceleration, there is reason to suspect that owners are motivated to uprate California engines to federal specifications. None of the rebuild shops has any incentive to keep statistics on the frequency of this occurrence. All the data collected on this subject came from the memories of shop superintendents through a follow-up telephone survey. The survey indicated that a request for uprating from California to federal specs is an infrequent occurrence. Several rebuild shops indicated that some manufacturers will not warrant a California engine that is uprated to federal certification specifications.

<u>Modifications to Fuel Injection Equipment</u>

All surveys collected data on this subject. Many modifications are possible. They include: increasing the fuel rate; advancing the timing; retarding the timing; replacing the fuel pump with an off spec pump (e.g., 49-state pump); use of the wrong injector spray tip; throttle delay disconnect; and incorrect injection pump calibration. Concerns about power and fuel economy were believed to stimulate high tampering rates for some of the above categories. Because of concerns about respondent honesty, questions on this subject were asked two ways: respondent experience and respondent perception of industry practice.

The perception of industry practice was always higher than shop experience. The overall average rate of fuel injection system modifications noted from in-house experience was 22 percent. High levels were noted for the following categories:

- incorrect injection timing, advance (15 percent)
- throttle delay disconnect (35 percent)
- incorrect injection pump calibration (30 percent)

These estimates are based on a review of the perception of industry practice, not in-house experience. This approach also produced a 10 percent estimate of incorrect turbocharger usage. Because the questionnaire was designed to overcome respondents' self-incrimination concerns, it is not possible to distinguish the respective contributions of rebuilding and tampering to the rates noted above.

Emissions Impact Due To Improper Rebuilds

Incorrect rebuilds cause emissions to be higher than the original zero-mile level after rebuild. They result in what is termed an "offset", an increase in emission level that is independent of mileage. This offset represents the difference in emissions improvements between properly and improperly rebuilt engines.

Fleetwide estimates of these offsets were produced by combining estimates of the emissions impact of each incorrect rebuild type with the rate of occurrence observed in the surveys. Three scenarios were developed to bound the range of possible impacts: low, base, and high.

The estimates from the base scenario indicate the emissions impact due to rebuilding can be significant. The base case increase for HC is 25 percent, and 3.4 percent for NOx. Particulate emissions,[1] while not explicitly calculated, are expected to increase at a rate in proportion to the increase in HC emissions. Close examination of the

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1. All diesel particulates measure less than 10 microns in diameter and are therefore in the respirable range.

individual contribution of each type of incorrect rebuild indicates that:

- injection pump calibration and maladjustment of the throttle delay disconnect are responsible for 80 percent of the excess HC emissions;

- advanced injection timing is responsible for over 67 percent of excess NOx emissions.

All of the above are service items; these maladjustments can occur during routine maintenance, as well as rebuild. Excess emissions caused by incorrect equipment replacements specifically identified as occurring in the rebuild process are low, and range from less than 20 percent of the emissions increase estimated for HC and 33 percent of that estimated for NOx.

1.2 CONCLUSIONS

Remanufactured engines constitute a minor portion of California heavy-duty engine sales. The emissions of these engines are required to match the levels from their earlier certification. There is no cause for concern, from an emissions perspective, from the sales of these engines.

Heavy-duty diesel engines experience several rebuilds in their lifetime. The survey data shows that an average engine receives 4 rebuilds and travels slightly more than 1 million miles in its lifetime.

No data could be found to show that aftermarket parts increase the emissions of HDDV's. Data were collected showing that much of the prevailing wisdom about aftermarket parts is incorrect: they are made to the same production specifications as OEM parts; they are often manufactured by the same company that supplies the OEM; and they are not always less expensive.

Uprating is a frequent occurrence and offers the potential to either increase or decrease the emissions of the base engine. The limited survey data collected in the study indicate that uprating from a California to a federal specification is an infrequent occurrence; therefore, no substantial emissions impact could be found from this practice.

Data collected in the survey indicate that fuel injection modifications are a frequent occurrence. Unfortunately, the survey design does not allow the distinction between injection system modifications that occur in the rebuild shop and those that occur in the field. The survey requested data on the frequency of improper modifications noted on equipment coming into the shop, as well as procedures employed in the shop. Generally, most shops denied performing improper injection system modifications but noted problems with equipment received for repair. The source of the improper modifications cannot be identified from the survey data. A much larger survey of maintenance, as well as rebuild shops, would be required to identify the source of the problem. Even then equipment modifications occurring in the field could only be estimated.

The HDDV emission impacts estimated from the survey results indicate that rebuilding can cause a significant increase in emissions. The Base Scenario produced an estimated increase of 11.86 tons/day of HC and 11.42 tons/day of NOx. The primary source of the fuel injection maladjustments causing the increase in emissions cannot be identified from the surveys. Based on numerous conversations with rebuild shops and fuel injection repair facilities, we believe that most of the injection modifications are occurring in the field, not in the rebuild shop. This leads us to the conclusion that servicing, not rebuilding, is the more significant source of excess emissions. This finding eliminated the need for recommending changes to rebuilding, reconditioning or remanufacturing practices in order to minimize increased emissions from improper procedures.

2. INTRODUCTION

2.1 OVERVIEW

During the past two decades, efforts to reduce the contribution of motor vehicle emissions to air pollution have focused principally on the development of emission standards and certification procedures for new vehicles. Despite the significant reduction in emissions achieved by light-duty vehicles in recent years, motor vehicles remain a major source of air pollution in California. Current regulatory efforts to reduce motor vehicle emissions are focused on two areas:

- the operation of an inspection and maintenance (I/M) program for light-duty vehicles to ensure that, as these vehicles age, the emissions reductions observed at certification are maintained; and

- the development of more stringent emission standards for heavy-duty diesel engines and the evaluation of the benefits of an I/M program for heavy-duty diesel vehicles (HDDV's).

Emissions from HDDV's are an important contributor to violations of health-based ambient air quality standards for nitrogen dioxide and inhalable particles in California. The emission standards in force today for these vehicles are substantially less stringent than those of light duty vehicles; regulatory efforts are currently underway to further reduce the emissions of new HDDV's.

Unlike light-duty engines, most of the mileage accumulated on HDDV's occurs after the engine has received its first major overhaul. This is a major source of concern to the Air Resources Board for the following reasons:

- Equipment changes made during the rebuilding or remanufacturing process can substantially degrade emissions performance.

- Because of the differences between California and federal emissions regulations, there is both acceleration and fuel economy performance degradation for vehicles certified to California standards. This degradation is suspected of influencing owners to request that California engines be rebuilt to the federal specifications or to use parts that improve performance but increase emissions levels.

- The long lifespan of HDDV's ensures that several rebuilds are likely to occur and that several opportunities for increasing emissions are available.

- The rebuilding process is unregulated, and the rate of occurrence of improper rebuilds is unknown.

- The influence of new HDDV regulations on air quality levels is diminished by the longer lifespan of older higher emitting HDDV's and the possibility that the emissions of these vehicles may be increased in the rebuilding process.

- In addition, there is a concern that <u>sales</u> of rebuilt, reconditioned, or remanufactured heavy-duty diesel engines, which do not conform with California certification requirements, may be a significant source of excess emissions.

Because of the concerns outlined above, this study was designed to determine the emissions impact of the rebuilding process on California heavy-duty diesel engines. It also addresses the emissions impact of the sales of rebuilt, reconditioned and remanufactured engines in

California. Surveys and site visits were used to collect information on the following issues:

1. the size of the heavy-duty engine rebuilding, reconditioning, and remanufacturing industry;

2. the engine upgrading or rebuilding, reconditioning, and remanufacturing practices used, noting any difference between California and federal rebuilding practices;

3. the number of rebuilt, reconditioned, and remanufactured engines (federal and California) sold in California.

To gain a better understanding of the industry and its practices, information was collected on the following subjects:

- typical mileage on engines at the time of rebuilding;

- sources of engines/components (new OEM versus aftermarket);

- rebuild, recondition, and remanufacture practices (California or federal certification, upgrade of components, use of OEM or aftermarket replacement components, etc.);

- specifications for major wear components used in the rebuild, recondition, and remanufacture process that are likely to influence emissions;

- quality control procedures used, including emissions tests;

- procedures for the identification of reconditioned engines;

- sales volume of HDDV's in California and nationwide;

- engine retail prices;

- engine and emission control system warranties; and

- expected useful life of the reconditioned, rebuilt and remanufactured engine.

After collecting and analyzing the data, an estimate of the emissions impacts of heavy-duty diesel engine rebuilding practices was produced.

2.2 APPROACH

To facilitate data collection, the project was divided into the following six task areas:

- identify the emission critical parts replaced during the rebuild procedure;

- target data collection efforts to selected segments of the rebuilding industry;

- design questionnaires that solicit relevant information from the selected market segments;

- identify survey samples for each of the selected market segments;

- execute the surveys; and

- compile respondent data and analyze the results.

In the first task, the available literature was reviewed to identify engine parts serviced or replaced during the rebuild process that could influence emissions. To augment the literature search, major heavy-duty engine manufacturers were contacted for their views on the emission critical parts and the procedures used in the rebuilding process that might affect emissions. The collection of this information was considered critical to the development of the survey questionnaires.

At the outset of the project, we recognized that there are several distinct segments in the rebuild industry. To form an accurate picture of the practices occurring in the industry, we decided to develop questionnaires that solicited information on the procedures and performance of each industry segment. This approach allowed the preparation of shorter, more specific questionnaires; it also increased the response rate of those surveyed by presenting a less onerous information request.

To help develop easily understood questionnaires, we prepared and distributed test questionnaires (Survey #1) to a series of California rebuilding firms. On the basis of the responses received to that survey, numerous changes were made to the format of questions and information requested in the other questionnaires.

An extensive effort was mounted to identify mailing lists of the selected industry segments. In some cases, this was quite easy as the names of engine manufacturers are well known, and mailing lists were readily available from professional associations. In other cases, professional associations refused to cooperate and forced the development of alternative survey samples. These alternatives included reviews of manufacturer parts and service directories and time-consuming reviews of telephone directories.

To maximize the response rate to the surveys, we included inducements to return questionnaires. These included free magazine subscriptions, summaries of survey responses, and telephone calls to remind/request participation. When responses remained low for a particular industry segment (e.g., California shops that work on fuel injection equipment), follow-up telephone calls were made to all non-respondents, and their responses to the critical questions were collected over the phone.

The information contained in the responses was computerized at the completion of each survey. A separate analysis of each of the surveys was conducted, and responses to common questions were compared for consistency. Inconsistencies noted in the responses were followed up through telephone contacts and field surveys.

The translation of the information collected in the surveys into an estimate of the incremental emissions impact on the fleet of heavy-duty diesel vehicles was divided into the following steps:

- the emissions impact of incorrect rebuild practices for emission critical parts was estimated through a review of available data, conversations with manufacturers, and engineering judgment;

- the rate of occurrence for each incorrect rebuild practice was estimated from the survey data to produce three scenarios that bounded the range of probable experience;

- the estimates of rate of occurrence were combined with estimates of the percentage emissions impact to generate the average emissions impact in gms/BHP-hr by model year 1977-1986 engines.

The estimates of model year emission impacts were then combined with available estimates of HDDV travel for 1986 to estimate the tons/day impact of improper rebuilding practices.

2.3 ORGANIZATION OF REPORT

This report is divided into six sections. Section 1 contains the Summary and Conclusions; Section 2 is the Introduction.

Section 3, Data Collection, provides an overview of the information requested in each of the surveys. It also identifies the segments of the rebuilding industry that received survey questionnaires. Summary statistics on the firms contacted, response rate, and quality of responses are presented.

Section 4, Overview of the HDDE Industry and Rebuild Practice, provides a brief discussion of trends in the heavy-duty diesel engine market in both California and the nation. A summary of the types of rebuilds possible is presented; emission critical components are identified. A review of the types of incorrect rebuilds possible and their impact on emissions is also presented.

Section 5, Summary of Survey Responses, presents the results of the analysis of the survey responses to issues/questions specified by ARB in the scope of work. Responses to these questions are organized to provide insight into the perspectives of fleets, rebuild shops, manufacturers and, when relevant, fuel injection equipment rebuilders. Separate analyses are also presented for California versus federal procedures and respondents.

Section 6, Emissions Impacts Due to Improper Rebuilds, presents a methodology to calculate the emissions impacts associated with incorrect rebuilds. Estimates of the emissions impacts due to incorrect replacement of individual components are developed. Scenarios estimating the rates of occurrence of each incorrect rebuild type are developed from the survey data. The emission impact of incorrect rebuilding practices on the vehicle fleet is produced by combining the estimates of occurrence with related emission impacts.

Appendix A contains two examples of surveys used in the study.

Appendix B lists part numbers for emissions critical parts for California engines.

Appendix C summarizes the information collected from site visits.

Appendix D contains a list of abbreviations/glossary.

3. DATA COLLECTION

3.1 OVERVIEW

The major challenge of this project was the development of a plan to collect sufficient data to determine whether the rebuilding industry is a major contributor to increased emissions levels in heavy-duty diesel engines. As discussed in the introduction, the difference in performance levels between California and federal HDDV's is known to motivate drivers to tamper with engines.[1,2] One of the key tasks in this project was to determine how frequently drivers request rebuilders to modify California equipment.

Because no independent data source on the quality of rebuilding practices exists, the primary data source for this project was the people doing the work. Thus, we were asking the people doing the work to be honest about how often they improperly rebuilt engines. Traditionally, surveys that ask self-incriminating questions are not viewed as reliable information sources; for example, misfueling estimates based on owner responses have been judged to substantially underrepresent the frequency of occurrence. Thus, one of the goals of the study was to collect information from a range of sources so that independent checks on the honesty/quality of the responses could be performed.

In addition to concerns about the quality of responses, the diversity of the industry dictated the development of either a very large questionnaire covering all facets of rebuild behavior or the

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1. Engine Manufacturer's Association, "Heavy-Duty Diesel Engine In-Use Emission Testing Meeting", briefing package for a presentation to the California Air Resources Board Staff, El Monte, CA, September, 11, 1985.

2. J. Hess, Midway Truck Service, Testimony at the EPA hearings on proposed heavy-duty NOx and particulate rules, Ann Arbor, MI, November 13, 1985.

development of smaller questionnaires targeted to a specific segment. Through telephone contacts with manufacturers and rebuild shops, it quickly became apparent that a small portion of the industry was qualified to work on fuel injection equipment. Therefore, we divided the industry into three segments: engine manufacturers; rebuilders; and fuel injection specialists. Further discussions and reflection added two additional segments: fleets and aftermarket parts suppliers. The final segment of the industry was specified in the scope of work, remanufacturers.

The decision to segment the industry and use smaller targeted questionnaires was supported by the fact that response rates decline as the length of the questionnaires increases. We were also concerned that we might only achieve the normal response to blind surveys, on the order of 1 to 2 percent. Because of the limited resources available to conduct the survey, we decided to use a trial survey to "test the waters" and revise the questionnaires on the basis of the test results. It was hoped that the improved questionnaires would increase the response rate of later surveys.

The remainder of this section presents a review of the information requested in the questionnaires, how questions were developed, an overview of the range of firms contacted, their response rate, and basic information about the firms that participated in the surveys.

3.2 QUESTIONNAIRE DEVELOPMENT

The approach used in the development of the questionnaires was to review the available literature, contact engine manufacturers, and devise questions that collected information related to issues outlined in the scope of work. The requested information in the test survey fell into the following categories:

- business practice;
- professional affiliation;

- number of rebuilds performed over the past year;
- makes of engines overhauled;
- mileage at rebuild;
- distinctions between in-frame and out-of-frame rebuilds;
- mileage between first and second rebuilds;
- percent of rebuilds caused by component failure;
- average cost of in-frame and out-of-frame rebuilds;
- components serviced during in-frame rebuilds;
- components serviced during out-of-frame rebuilds;
- use of California versus federal specification parts;
- knowledge of injection system modifications;
- use of instruments to measure gaseous emissions;
- conduct of power or fuel consumption measurements;
- uprating experience;
- use of rebuilt, reconditioned or remanufactured injection equipment;
- experience with rebuilding injection equipment;
- performance of bench tests on injection equipment; and
- knowledge of regulations prohibiting engine modifications during rebuild.

In addition to the above questions, the survey included an up-front explanation of the purpose of the survey and definitions used in the survey. An additional three pages were required to accommodate the questions from a related ARB contract evaluating the potential benefits of a HDDV I/M program. All of the aforementioned information requests led to a test questionnaire length of 10 pages. To minimize the amount of paper the reader is required to digest in reviewing this study, copies of selected questionnaires used in this study are included in Appendix A.

To stimulate the response rate of the test survey (Survey #1), a free magazine subscription to selected "industry" publications was offered if the questionnaire was returned within two weeks of the initial mailing. A total of 48 questionnaires was sent out; 17 responses were received for a 35 percent response rate. The responses fell into three categories:

- engine rebuild shops (6)
- injection rebuild shops (9)
- no information (2)

The responses from the engine rebuild shops contained the best responses of the survey. These shops averaged approximately 31 in-frame and 32 out-of-frame rebuilds per year. They also completed most of the questions related to mileage between rebuilds and the cost of the rebuilds. Almost no information was provided on fuel injection equipment modifications; most respondents indicated that they did not work on injection equipment.

The responses from the fuel injection equipment shops were very disappointing. Most of these respondents did not conduct <u>engine</u> rebuild work and could not answer the bulk of the questions contained in the survey. Their responses pointed out the relatively small amount of information requested about the type and quality of injection, turbocharger and governor repairs.

Two of the responses contained no useful information because their primary business practices related to work on locomotives and garden equipment, respectively. These responses provide an indication of some of the pitfalls associated with the collection of survey samples from telephone books.

Only 2 of the 17 respondents provided any answers to the three pages of questions included from ARB's project investigating the potential benefits of HDDV I/M. It was clear from the above responses that the questionnaire had to be shortened. This was achieved by developing a separate questionnaire for fuel injection rebuilders, streamlining existing questions and eliminating the page of definitions contained in the original survey.

The promise of a magazine subscription appeared to dramatically increase the response rate above that of normal blind surveys. Unfortunately, there were insufficient resources available to continue that offer. Therefore, summaries of responses from competitors were instead substituted as inducements to increase the response rates. The test survey also provided space for respondents to identify themselves and their telephone numbers if they wished to further participate in the survey. The mixed response to this option convinced us to make that portion of the questionnaire optional and to further guarantee all participants anonymity. For this reason, none of the participants will be identified in this report.

3.3 ENGINE MANUFACTURERS

An integral part of the overall survey was to maintain open lines of communication with the major domestic manufacturers of diesel engines used in highway vehicles. We contacted four major domestic manufacturers:

- GM/Detroit Diesel Allison (DDA)
- Caterpillar Engine Co.
- Cummins Engine Co.
- International Harvester (IH)

The central contacts for each manufacturer were: Mr. John Fisher, DDA; Mr. Don Dowdall, Caterpillar; Mr. John Hendricks, Cummins; and Mr. Chuck Hudson, International Harvester. Each manufacturer assisted our effort in a variety of ways. The assistance provided by these manufacturers included assembly of technical staff for a meeting on rebuild issues, coordination of responses to the questionnaire, identification of differences between California and Federal vehicles emission control technology (and their appropriate part numbers) and technical support for estimates on the emission effects of rebuild. In addition, our contacts provided innumerable small pieces of data, such as sales of engines in California, warranty rules, etc.

Each of the four manufacturers was visited for a meeting covering technical and market-related factors affecting rebuild. At these meetings, detailed information was provided on all of the parts that could conceivably affect engine emissions, parts that were normally changed during an "in-frame" or "out-of-frame" rebuild, and the types of incorrect rebuild that could occur in the field. The information gathered at these meetings was utilized to develop Section 4 of this report.

Questionnaire responses were coordinated by the individuals named above and were utilized to provide manufacturers' perspectives on what should occur during rebuild, as well as what actually occurs in the field. The manufacturers' responses served as a standard to rate the responses received from the field. Much of the information contained in these responses is presented in Chapter 5 of this report. Sales data of new and remanufactured engines are presented in the appropriate sections, while information on part numbers for California versus 49-state engines is detailed in Appendix B. Part number data were used in site visits to rebuild facilities to determine if 49-state specification parts were being used instead of California specification parts.

Insights into the range of projected emission effects of incorrect rebuilds was provided by technical personnel of each manufacturer. We have used their general and technical insights to quantify the range of emission effects associated with an incorrect rebuild of each component. These data are discussed in Section 6.

3.4 FUEL INJECTION REBUILD SHOPS

From a review of the responses received in Survey #1, it became clear most fuel injection rebuilders belong to a professional organization named the Association of Diesel Specialists (ADS). The ADS membership specializes in the repair of diesel fuel injection, governor and turbocharger systems. ADS is comprised of companies and individuals whose primary focus is on the service of these systems. Current membership numbers almost 800 members worldwide and approximately 324 members in the U.S. A copy of the names and addresses of the entire membership was obtained from ADS' Directory of Members and Services. From this catalog, a mailing list of approximately one half of the U.S. members (158) was compiled.

A new questionnaire was prepared (Survey #2) to specifically collect information on the experience of ADS members; subjects addressed included:

- makes of injection equipment serviced;
- mileage before first overhaul and between first and second overhaul of injection equipment;
- labeling of work completed;
- cost of overhauls;
- repair practices for California and federal equipment;
- frequency of modifications to fuel injection equipment;
- difference between quality and availability of new and aftermarket replacement parts; and
- warranty for service conducted.

A total of 43 responses was received for a 27 percent response rate. The response of California ADS members was substantially lower; out of the 11 questionnaires sent, only 2 were received. Only one of these responses was useful because the other respondent specialized in light duty vehicles. Thus, we had an excellent summary of rebuilding practices outside of California and almost no data on practices inside the state. The out-of-state data were nevertheless useful because many of the members indicated working on California equipment. To fill the gap in California information, each of the non-respondents was contacted by telephone to collect answers to the survey. All but two were cooperative in sharing insights from their experience.

In general, the quality of the responses from the ADS membership was quite good. It was not uncommon to find additional comments penciled next to their answers.

3.5 FLEETS

A large portion of the HDDV's sold are purchased and operated by trucking fleets. Fleets are generally used to satisfy either a company's internal transportation needs or those of others on a "for hire" basis. The important feature of fleets is that their maintenance practices are not determined by drivers, as is the case by owner operators, but by a centralized service department. The sophistication of the maintenance varies depending on the size of the fleet, its purpose, and management's knowledge, and interest in controlling costs.

Large fleets (e.g., over 1,000 vehicles) maintain service departments that set rigorous maintenance schedules and use computerized data bases to track the performance of their vehicles. These systems can be quite sophisticated and are used to track the performance of mechanics, procedures, parts, and engines. This information is used to support purchasing decisions of both engines and parts. Smaller fleets, on the order of 10 to 20 vehicles, may employ mechanics to keep the vehicles operating but offer little sophistication in maintenance practices. Often management's knowledge of shop operations is rudimentary, and the only communication or guidance is to control short-term costs.

While the above descriptions are oversimplistic in characterizing the sophistication at either end of fleet operations, they do provide a glimpse of the bounds of the quality of operations observed in the survey. Recognizing that this industry is tightly knit and might be suspicious of the survey, we hired an industry consultant, Lou Hoffman, to conduct the survey (Survey #3). Mr. Hoffman is a former rebuilding shop superintendent for PIE and extremely knowledgeable in HDDV maintenance and rebuilding procedures. His long experience and contacts in the rebuilding industry made him an excellent candidate to collect the required survey data. Sierra contracted with Mr. Hoffman to supply the following information:

- 10 to 15 completed surveys from large fleets;
- 30 completed surveys from small fleets;
- clarification of responses with telephone interviews; and
- identification of facilities for site visits.

To provide the maximum coverage of fleets for the survey, Mr. Hoffman agreed to collect equal amounts of responses from California and from the rest of the country. He also agreed not to focus on large fleets in either of the specified categories, but to collect data from a range of fleets with varying levels of sophistication in their maintenance procedures. Mr. Hoffman provided guidance in the development of the fleet questionnaire. Questions were added on the following issues:

- use of an oil analysis program;
- percentage of major cores rejected;
- use of a tear down analysis;
- air cleaner maintenance practices;
- knowledge of previous rebuild;
- distinction between in-house and out-of house rebuild rates and costs.

To minimize the length of Survey #3, several questions included in the test survey were either eliminated (e.g., warranty issues are not relevant for work done in-house) or repackaged.

A total of 80 questionnaires was mailed; 44 useful responses were received for a 55 percent response rate, with an equal split of California and non-California responses. The distribution of large and small firms is a little more difficult to characterize; however, responses were received from firms that conducted as little as 1 in-house in-frame rebuild over the past year to as many as 2,000 in-house out-of-frame rebuilds in the same time period. Many of the responses indicated a relatively small number of rebuilds over the past year for relatively large, well-known firms. The discrepancy was caused by the fact that maintenance operations for national fleets are often fragmented to regional locations, and the respondent provided data based on the number of rebuilds that occurred at that location.

Overall, the quality of the responses was quite good, and Mr. Hoffman conducted numerous follow-up phone calls to resolve inconsistencies and to collect additional information.

3.6 INDEPENDENT REBUILD SHOPS

Sierra originally proposed to work with the Automotive Engine Rebuilders Association (AERA) to collect information on rebuilding practices employed outside of the fleets. AERA has a U.S. membership estimated at approximately 3,000 members and was felt to be an ideal contact for this effort. Unfortunately, after contacting the national headquarters and submitting a formal request, complete with a sample questionnaire, we were informed that, after consideration by their Board of Directors, they declined to participate.

The original fall-back position was to collect the addresses of rebuild shops from the business yellow pages for urban areas across the country. Given our experience with the test survey and the identification of locomotive and garden equipment repair facilities, we were not encouraged. Conversations with various shops and maintenance personnel instead led us to use engine manufacturer directories of service facilities.

Each of the major domestic engine manufacturers publishes service directories for use by drivers in locating qualified repair facilities. These publications are quite sophisticated, and some contain maps for many of the facilities in the larger urban areas. They also identify whether the shop is a dealer or an independent and the OEM that the shop is qualified to repair. Many of the shops are qualified to repair more than one manufacturer's engines.

Directories were obtained from three of the major domestic engine manufacturers: Caterpillar; Cummins; and Detroit Diesel Allison.

From these directories, we identified the facilities specializing in the repair of four of the major manufacturers. Facilities specializing in the repair of International Harvester engines were added to the three listed above. The addresses of 466 separate facilities were selected for the rebuild shop survey (Survey #4). Each manufacturer was assigned two mailings, one for California and one for non-California facilities. A category for independents was also added to the list, for a total of nine categories.

The questionnaire employed in this survey was similar to the one used in the fleet survey. Several changes were made, however. They included questions about the following issues:

- whether they could tell if an engine had been rebuilt before and how they recognized previous work;
- frequency of spec plate removal;
- average number of rebuilds and lifetime miles that an engine block will receive before it is beyond repair; and
- the percent cost of rebuilt engines in comparison with new engines.

The response rate for Survey #4 was the lowest of the study; only 50 responses were received, for a response rate of 11 percent. The rate for California facilities was approximately equal to that for those outside the state. An exact number cannot be specified because many of the independent respondents chose not to identify themselves. The response rates were too low to provide statistically valid information on the practices of facilities specializing in the repairs of a particular engine manufacturer. However, in aggregate, they ensured that a broad distribution of responses was received.

The quality of the responses was generally good, and many of the respondents were helpful in answering follow-up questions, particularly California respondents.

3.7 AFTERMARKET PARTS SUPPLIERS

At the outset of the study, it was suspected that non-OEM parts used in the rebuild process might contribute to an increase in emissions. For that reason, many of the questions included in the questionnaires were designed to collect data on the use of these parts. The conventional wisdom was that parts sold in the aftermarket were not produced under the rigid specifications set by manufacturers for their products. Because these parts did not have to meet these specifications, they could be made at a lower cost and therefore sold at a lower cost. Lower cost parts were suspected of appealing to drivers trying to cut maintenance costs and to less sophisticated maintenance shops.

As the study progressed, the information collected seemed to contradict the conventional wisdom outlined above. First, because very few of the respondents admitted to using aftermarket parts, little information was available. Conversations with manufacturers, particularly DDA, indicated a certain level of respect for the quality of the parts sold in the aftermarket, and an acknowledgement that they were a competitive force that was monitored. Further conversations with fleet managers indicated that some aftermarket parts were used, and that in many cases they were equal in quality to OEM parts. Mr.

Hoffman indicated that when he ran the PIE rebuild shop, one of the engine manufacturers maintained a parts person on-site because of the volume of parts used, but also because of quality problems. Evidently it is a common practice to "mike" all parts, OEM and aftermarket, before they are used in many rebuild shops.

The above information led to a conversation with the engineering department of the largest aftermarket parts house, Korody-Colyer. In that conversation, we learned that Korody-Colyer purchases many of its parts from the same parts producers as the OEM's do, and that they maintained in-house staffs to statistically sample parts for variations in dimensional tolerances and maintain quality control.

On the basis of the above information, we decided to further explore the aftermarket parts industry to identify parts sources, production specifications, and quality control procedures. These efforts focused on emissions critical parts, those we had identified as having the potential to increase emissions when changed during the rebuild process. The following aftermarket parts suppliers were contacted:

- Korody-Colyer;
- Dipaco;
- Pro Diesel;
- McBee Supply Corp.

Additional effort was expended to identify those component manufacturers that supplied parts to both the OEM's and to the aftermarket parts houses. Effort was also expended in the collection of prices for selected emission critical OEM and aftermarket parts. We wanted to determine whether the price relationship theorized for OEM and aftermarket parts was correct.

3.8 <u>SITE VISITS</u>

The final source of data employed in the study was the inspection of rebuild facilities through a site visit. There were several purposes in these visits: to gain a practical appreciation of the rebuilding process, to observe the different procedures, and to determine whether there were any differences between California and federal rebuilding practices. Several shops were visited; however, because of the promise of anonymity, none are listed here. One additional use of the visits was to actually see if California spec parts were being used in the rebuild process. This objective was almost impossible to achieve because it required visually observing the part numbers on the replacement parts. This indicated to our host that we did not trust what he told us and was not the basis for a comfortable sharing of information. The rapport necessary to make this request was established with only one rebuild facility. The results of that discussion will be presented later in the report.

4. OVERVIEW OF THE HDDE INDUSTRY AND REBUILD PRACTICE

4.1 INTRODUCTION

Although EPA and the ARB classify all engines used in trucks over 8,500 lb GVW as heavy-duty, the engines can be further classified into three distinct groups labelled as light-heavy, medium-heavy and heavy-heavy. Diesel engines are sold in all three categories of trucks and the relationship between engine categories and truck weight classes is as follows:

- Light-heavy diesels are typically used in trucks of 8,500 to 14,000 lb GVW;

- Medium-heavy diesels are typically used in trucks of 14,001 to 50,000 lb GVW;

- Heavy-heavy diesels are used in trucks over 50,000 lb GVW.

It would be incorrect to assume that these engine usage categories are exact; they reflect typical usage, but there are some trucks especially in the 14,001 to 50,000 lb GVW category that may utilize either a light-heavy diesel or heavy-heavy diesel depending on the application and duty cycle of the particular truck. It should also be noted that truck manufacturers are typically different from engine manufacturers, and the engine is certified for sale without any specific relation to the truck in which it will be used.

There are five truck diesel manufacturers in the U.S. - GM/DDA, International Harvester, Caterpillar, Cummins and Mack. GM/DDA is unique in offering a full range of diesel engines across all three markets, while International Harvester (IH) specializes in the light and medium markets; Caterpillar in the medium and heavy markets; and Cummins and Mack in the "heavy-heavy" market only. Cummins has recently begun building engines for the light and medium markets, but sales in those markets have been negligible to date. Several European manufacturers have been selling engines in each of the three submarkets since the late 1970's but their total penetration in any of the three classes has been small (less than 5 percent) to date. Starting in 1986 several Japanese manufacturers (Isuzu, Nissan, Hino) have entered various segments of the truck market, but their overall penetration is also quite small.

4.2 MARKET SHARES BY MANUFACTURER

In the light-heavy duty diesel engine market, the IH 6.9 litre and the DDA 6.2 litre have nearly equal market shares, but both engines were introduced relatively recently (1982). Moreover, this segment of the market is similar to the light-duty truck market where little rebuilding takes place. Because of this and the lack of any real experience in rebuilding such engines, this segment of the market is not considered in this report.

In the medium-heavy duty market, the competition is primarily between IH, Caterpillar and DDA, as shown in Table 4-1. Caterpillar sells the 3208 at the premium end of the market, DDA sells the 8.2 litre at the low-priced end of the market, while IH occupies the middle ground with its DT-466 series and the low volume 9.0 litre. IH also sells most of the engines for the school bus market, and their engines are the 9.0 litre or upgraded versions of the 6.9 litre.

In the heavy-heavy engine market, Cummins sells 55 percent of the total with its L10 and NTC series engines. Caterpillar and Mack have 15 and 20 percent shares of this market with the 3406 and ENDT series, respectively, while DDA's 71 and 92 series have only eight percent of the total market. DDA, however, sells nearly all of the bus engines used in transit or intercity buses. DDA's heavy-heavy diesels are unique in being the only 2-cycle engines on the market.

TABLE 4-1

FACTORY SALES BY MANUFACTURER
HEAVY-DUTY DIESEL ENGINES

Light-Heavy	1984	1985
IH	64,055	67,444
GM	98,024	80,773
Medium-Heavy		
Caterpillar	23,951 (231)*	22,782 (209)
IH	33,017 (7414)	39,527 (14,192)
GM/DDA	16,539	28,937
Import**	4,592	4,709
Heavy-Heavy		
Caterpillar	21,206	22,688
GM/DDA	11,629 (3705)	10,687 (5,298)
Cummins	92,273	78,233
Mack	27,692	27,063
Volvo/White	740	625 (112)

*Numbers in parentheses represent the number of bus engines sold.

**Mostly Mercedes-Benz engines.

Source - MVMA, sales from U.S./Canada plants, FS-3.

The California diesel engine markets are very similar to the national markets in terms of product offerings and market shares. For this analysis, four of the five major manufacturers were contacted, and they provided sales of engines in California. These figures are shown in Table 4-2.

4.3 ENGINE REBUILD DEFINITIONS

At the end of medium-heavy duty or heavy-heavy duty engines' useful life, the owner usually rebuilds the engine to obtain additional service at lower cost than through the purchase of a new engine. Unlike the light-duty engine, or even possibly the light-heavy duty engine, some medium-heavy and most heavy-heavy duty engines are designed so that many core components, such as the engine block and crankshaft, have a useful life of up to 1,000,000 miles. Their design also facilitates easy replacement of components subject to high wear and tear, such as pistons, cylinder walls, etc. The industry distinguishes between three types of rebuilding, namely:

- In-frame rebuild
- Out-of-frame rebuild
- Remanufacture

In-frame rebuilding usually is the first rebuild for a heavy-heavy duty engine, and occurs without removal of the engine from the truck. Typically during an "in-frame" rebuild, the piston rings, cylinder liners and valves are replaced, the injection system recalibrated, the injectors and head disassembled and cleaned, and accessories such as the oil pump rebuilt or replaced. In some cases, the turbocharger cartridge is replaced, as are the rocker arms and cam followers, if necessary. For most medium-heavy diesels, this is usually the only type of rebuild performed.

An out-of-frame rebuild requires that the engine be lifted out of the truck and rebuilt on a stand. The out-of-frame rebuild is much more extensive than the in-frame rebuild, and includes all of the typical activities for an in-frame rebuild. Over and above those activities,

TABLE 4-2

CALIFORNIA NEW HEAVY-DUTY DIESEL ENGINE SALES
FOR SELECTED MANUFACTURERS

Light-Heavy	1984	1985
GM/DDA 6.2 litre	N/A	N/A
IH 6.9 litre	11,414	13,768
Medium-Heavy		
IH DT-466/9.0 litre	2,643	2,845
DDA 8.2/8.2T	3,182	3,453
Caterpillar 3208	719	1,270
Heavy-Heavy		
Caterpillar 3406/3306	907	1,535
DDA 71 series	326	146
DDA 92 series	1,084	1,029
Cummins NTC series	3,744	4,056

the cylinder block may be machined, the crankshaft reground, the engine main bearings changed, the camshaft replaced and the aftercooler either rebuilt or replaced. Most of the optional items for an in-frame rebuild, such as replacement of the turbocharger cartridge, rocker arms, etc., are usually performed in the out-of-frame rebuild. Medium-heavy diesels are rarely subjected to an out-of-frame rebuild.

Remanufacturing requires that the old engine be sent to a manufacturing facility, where it is completely stripped to the base block. Reassembly entails using a larger number of new parts in comparison to an out-of-frame rebuild, but the types of parts replaced are generally similar. Of course, in the centralized facility, the remanufacturing process is on an assembly line and once the old engine is stripped and then reassembled, parts retained from the old engine may be used in conjunction with a different block (i.e., the identity of the engine components will be lost in the remanufacturing process). Due to the centralized and more thorough nature of remanufacturing as opposed to rebuilding, a remanufactured engine is expected to be more durable than a rebuilt engine. Remanufacturing is generally preferred for medium-heavy diesels, but is not common for heavy-heavy diesels.

As explained above, the actual components replaced in any of the three types of rebuilding show considerable overlap. Given the ARB's interest in the emissions effect of rebuilding, our analysis has concentrated on components replaced during any or all types of rebuilding, and the range of potential effects on emissions.

4.4 EMISSION CRITICAL COMPONENTS

A large number of components replaced during the rebuild process are unrelated to emissions but may affect the durability of the rebuilt engine. This is not an issue of concern to the ARB, and, as a result, our effort was to isolate the components most responsible for emission formation and control. The identification of such components was based on an engineering analysis and discussions held with technical staffs of the major domestic diesel engine manufacturers.

The entire combustion process is governed by the quantity of air, the quality of fuel and the rate of mixing of the two within the combustion chamber. Components affecting any of these three variables are, therefore, likely to affect the emission performance of a rebuilt engine.

Components affecting the quantity of air supplied to the combustion chamber are the turbocharger, the intercooler, and in the case of DDA heavy-heavy duty engines, the blower. Components affecting the quantity of fuel delivered to the combustion chamber are the fuel injection pump and the injector. Components affecting the air-fuel mixing process are the piston, the injector tip and the camshaft, which governs the timing of fuel injection and valve opening duration. It is possible that, during rebuild, incorrect components of the above type are used and the emissions of the rebuilt engine are higher than certification levels. This can occur because heavy duty engines of the same model are built to a variety of horsepowers and rated speed specifications. Each specification is based on a unique combination of parts that are dimensionally and functionally similar but calibrated to different specifications. Because of the dimensional and functional similarity, however, parts belonging to one engine calibration will generally fit an engine requiring a different part. For example, the Cummins NTC series is available in 6 or 7 different horsepower and rated speed specifications federally, and 3 or 4 different California specifications. Parts such as the injector or piston from one specification can be incorrectly used in an engine of different specification. A discussion of the specific effects of each component is given below.

The <u>turbocharger</u> provides a supply of high pressure intake air to the engine. The compressor size and aspect ratio are important variables governing the performance of this component. Since the characteristics of turbomachinery are very different from those of piston engines, the airflow characteristics of the turbocharger can be matched to those of the piston engine only in certain operating ranges. The matching of these characteristics define the torque and horsepower peak of the engine; a different turbocharger may provide more air in some operating regime of engine operation at the expense of less air in some other regime. As a result, turbocharger mismatch can cause emissions to increase in certain operating modes.

The aftercooler is used to reduce the temperature of air leaving the turbocharger. The lower temperature air results in delivery of cooler, denser air into the cylinder. The use of an improperly sized aftercooler or removal of the aftercooler will result in increased NOx emissions and, to a smaller extent, increased HC emissions.

The blower, used in DDA 71 and 92 series engines only, is similar to the turbocharger in function, except that the range of RPM over which the blower supplies air is far higher. As with the turbocharger, there is a possibility of a mismatch, resulting in higher HC and particulate emissions.

The fuel injection pump meters the fuel in most engines (except DDA) and also pumps it to very high pressure suitable for injection in Caterpillar and IH engines. The fuel metering function depends on both the throttle position control and the governing settings. In addition, the fuel injection pump also contains metering control for transient operating modes. The four major diesel engine manufacturers contacted for this study - Cummins, Caterpillar, IH and DDA - utilize substantially different fuel injection systems.

The DDA engines utilize the so-called "unit injector" where each cylinder has a completely separate metering and high pressure unit that is integrated into the cylinder head. Metering is accomplished by varying the effective stroke of the high pressure plunger. Since each individual injector is metered separately, all injectors in an individual engine must be indexed with respect to the common injector control tube controlling all injectors. The injector control tube is connected to governor/throttle by means of a fuel rod assembly. In general, most DDA engines use a high/low governor although the all-speed governor is available as an option. Fuel injection at high pressure is accomplished by a rocker arm on the camshaft depressing the plunger for each injector. Injection timing is set by adjusting the injector follower height in relation to the injector body.

Cummins engines also utilize a high pressure injector system driven by the camshaft through a rocker arm assembly, but fuel metering is done separately with the aid of a metering pump. The metering pump uses the pressure-time system where fuel pressure feeding the injectors (rail-pressure) is modulated through an orifice. Cummins engines use a hi/low governor typically, although an all-speed governor can be specified as an option, in most of their heavy-duty engine lines.

Caterpillar and IH engines utilize a separate high-pressure in-line fuel injection pump much like the Mercedes light-duty diesel pump, although the governor used is typically an all-speed governor. The discussion above illustrates the difficulty in deriving a common list of rebuild practices for these different system types.

Injection timing is a critical determinant of emissions in HDDV's. In contrast to light-duty vehicles, timing retard causes increased HC and particulate in direct injection diesels. Very large increases in HC/particulate occur with excessive timing retard, but the fuel consumption is also increased, providing little incentive for such an incorrect rebuild. Timing advance is also possible, with fuel economy benefits accompanied by increased NOx emissions. Since many California engines feature timing retarded from optimum, advancing the timing during rebuild is more likely. However, injection timing is difficult to change in DDA and Cummins engines and requires removal of the camshaft or major disassembly of the engine block. Thus, incorrect setting of timing is more likely to occur in an out-of-frame rebuild.

The elimination or tampering of the smoke-puff limiter or air-fuel control may be common according to most manufacturers. This device limits the fuel during transient acceleration until the inlet pressure of air is high (i.e., the turbo boost is available) and tampering with this device is an easy way of obtaining more power during transients, albeit with high HC/particulate emissions. In DDA engines, the fuel rod activates the injector control tube through this device; the device is merely a dashpot that translates a transient acceleration to a slow increase in the control tube motion and effects a delayed throttle response. In Caterpillar engines, the device limits rack travel as a function of boost pressure, while in Cummins engines, the fuel rail pressure is bled off as a function of boost pressure. The DDA and Caterpillar devices can be completely disabled or removed, while the Cummins device can be adjusted so that the bleed is minimized. This setting can be changed either at rebuild or during routine maintenance.

The setting of the governed speed is another possible common maladjustment during rebuild. Depending on the governor, these may be separate control settings for the maximum speed and the maximum fuel quantity or in some cases, only the setting for speed. With many systems (e.g., Cummins), changing the governor maximum speed setting also causes changes in the entire maximum fuel flow curve, leading to high HC/particulate emissions. In most cases, this setting can be changed by an adjustment screw, which is sealed. However, many heavy-duty truckers are known to tamper with this setting to provide speed increases; in fact, special tools (called "stingers") are available to adjust this setting after drilling out the protective covers. Since this is a service item, it can be maladjusted during rebuild or service.

The injector controls the rate of air fuel mixing by determining the degree of atomization of the fuel at the start and end of injection. The spray tip is an important part of the injector as it optimizes the fuel spray for the combustion chamber shape and air swirl. In addition, the sac-volume which determines the amount of fuel trapped in the injector tip at the end of injection, also determines emissions. Both the use of an incorrect spray tip or a high sac volume injector increases HC and particulate emissions.

The piston is important due to the fact that most heavy-duty engines have the combustion chamber cast into the piston bowl. The shape of the chamber aids in the air fuel mixing process by enhancing swirl and "squish", terms that refer to the flow of air in the combustion chamber. Emissions are optimized by matching combustion chamber shape to air-flow and injection characteristics. Use of the wrong piston can lead to increased HC and particulate emissions.

4.5 TYPES OF INCORRECT REBUILD

A key decision in both the conduct of the survey and the estimation of emission impact was on the types of incorrect rebuilds required for consideration. Each engine has an identification number which dictates the specification of all emission control part numbers for rebuild. Manufacturers have informed us that, for the most part, mechanics simply follow this part number list during rebuild. Discussion with the technical staff of the manufacturers revealed that the possible use of incorrect components could be classified into three types:

- Use of 49-state versus California parts
- Use of parts of older vintage designs than those required
- Use of non-OEM components

Because of the similarities between California and 49-state engines of a given model year, it appeared both likely and probable that

California engines could be rebuilt to 49-state specifications. In particular, it is widely known that the California specification suffered some loss in fuel economy in comparison to the equivalent 49-state engine, and several high power ratings are unavailable in California specification. A review of the California and federal emissions standards and the design changes needed to meet the standards is provided below, and the resulting differences in emission critical components recognized.

Prior to 1977, heavy-duty engine emission standards were set based on gasoline engine requirements, and the unmodified diesel engine could generally meet the applicable standards with few exceptions. California's 1977-1979 standards represented the first hurdle for diesel engines, while the 1979 federal standard was the first year that federal engines required any emission control based modifications. Table 4-3 shows the standards in force; California's 7.5 g/BHP hr NOx standard was more stringent than the uncontrolled engine's 8-9 g/BHP hr. As a result, manufacturers chose to retard injection timing to meet the standard, and several of the highest emission rated engines were simply discontinued for California. Both federal and California engines featured advanced low-sac injectors since 1977 and HC emissions were typically well below the applicable 1.5 g/BHP hr standard (based on the HFID measurement method).

Starting in 1980, California's standards were made substantially more stringent than the federal standards and meeting the standards required extensive re-optimization of the airflow characteristics, compression ratio, fuel pump calibration and injection timing on most engines. The manufacturers were asked to provide a list of emission critical parts that were different between California and federal engines. Differences in emission related components are summarized in Table 4-4 for the most popular medium-heavy and heavy-heavy engines discussed in Section 4.2.

TABLE 4-3

COMPARISON OF EMISSION STANDARDS
CALIFORNIA VERSUS FEDERAL
(g/BHP-hr)

	Federal		California	
	HC	NO_x	HC	NO_x
1977 - 1978	16 [HC + NO_x]		1.0*	7.5
1979	1.5	10	1.5	7.5
1980 - 1983	1.5	10	1.0	6.0
1984 - 1986 (transient)	1.3	10.7	1.3	5.1

*Different measurement method, equivalent to 1.5 standard for 1979 using HFID method.

Table 4-4

DIFFERENCES BETWEEN CALIFORNIA AND FEDERAL ENGINES 1980-1986

Engine	Injector	Fuel Pump	Blower	Turbo	Intercooler	Camshaft	Pistons
DDA							
8.2L NA	x	N/A	-	N/A	N/A	-	-
8.2L TC	1/80-5/81 only	N/A	-	-	-	-	-
6V-92TA	x	N/A	9/81-12/83	x	-	x	-
8V-92TA	x	N/A	x	x	-	x	-
IH							
DT-466 A210F DTI-466 A210C	x	x	N/A	-	x (not in Fed)	-	-
DT-466 A180F DT-466 A180C	x	x	N/A	x	N/A	-	-
Caterpillar							
3208 NA	-	x (+ drive gear)	N/A	N/A	N/A	-	(only 1985+)
3208 T	-	x (+drive gear)	N/A	x	-	-	(only 1985+)
3406	x	x	N/A	x	-	-	-
Cummins							
NTC series	x	Setting only	N/A	x	-	x	x

Starting in 1984, a new test procedure was adopted which changed the standard numerically, but was not substantially more stringent than the previous steady-state test procedure based standards for both California and 49-states. As a result, most of the design differences present between California and federal engines in the 1980-1983 period continue for the 1984+ period; exceptions to this rule are noted in Table 4-4. Manufacturers also provided part numbers for California and federal engines for each type of emission critical component identified; these part numbers were used in the survey to identify incorrect rebuild practices and are included in Appendix B.

The second type of incorrect rebuild was associated with using older model year specification OEM parts, e.g., use of older high-sac volume injectors rather than the newer types. Manufacturers were of the opinion that this would be unusual since there was no real economic or performance incentive to utilize older design parts, and believed that it may occur only as a result of newer parts being out-of-stock or due to mechanic error.

The third type of incorrect rebuild was associated with the use of non-OEM parts. Little information is available as the quality of non-OEM parts and all evidence of their emission performance is purely anecdotal. The use of such parts may occur because they are lower priced in comparison to OEM parts. In general, manufacturers believe that the problem associated with the use of non-OEM parts is generally one of durability, not emissions. However, manufacturers believe that some types of non-OEM parts, such as the injector or turbocharger, may not incorporate all of the design changes for that specific engine rating, and non-OEM parts may not distinguish between federal and California ratings.

Accordingly, one model for estimating the influence of non-OEM parts would be to treat them either as a federal specification OEM part used to rebuild a California engine, or as equivalent to an older model year design of the same part. This would be a worst case assumption, since many non-OEM parts are identical to OEM parts. This occurs because heavy-duty engine manufacturers purchase a wide variety of emission critical components, such as injection nozzles, pistons, camshafts, etc., and the supplier corporation can independently market the same part as a "non-OEM" part in the open market. However, the assumed effects of using a non-OEM part are appropriate as an upper bound to possible emission impacts.

One additional area of concern to the ARB is in "uprating" of engines during rebuild. This refers to rebuilding an older engine to a newer specification, possibly to a higher horsepower specification. Since each engine is offered at several different horsepower ratings (all meeting standards), it is possible to rebuild an engine to a more modern specification of higher horsepower that can result in a net benefit to emissions. Since some specifications of horsepower are available only in 49-states and not in California, uprating in some cases may result in rebuilding an engine to 49-state specification. This, of course, is functionally equivalent in emission impact to utilizing 49-state instead of California components, but there are no additional emissions specifically associated with a higher horsepower rating.

5. SUMMARY OF SURVEY RESPONSES

5.1 INTRODUCTION

Information on many aspects of the rebuilding process was requested in the surveys employed in this study. Additional insights were gained through telephone contacts and through site visits. The presentation of the results is complicated by the diversity of views collected in the study and the range of issues covered. To simplify the presentation of the survey responses, only selected topics, either those specified by ARB in the scope of work or topics that we feel are of particular interest will be presented in this section. The following issues will be discussed:

- number of remanufactured engines sold in California;
- mileage between rebuilds;
- rebuild frequency and expected useful life;
- rebuilds costs;
- use of aftermarket parts;
- component servicing practices;
- frequency of uprating;
- warranty coverage;
- spec plate removal;
- quality control procedures; and
- rebuilding specifications.

The approach used in presenting the results for each of these categories will be to discuss view points from all of the relevant data sources and to reach a conclusion when possible. Being mindful of ARB's interest in differences between California and federal experience, three sets of statistics will be presented when relevant: California, federal, and total.

5.2 NUMBER OF REMANUFACTURED ENGINES SOLD IN CALIFORNIA

One of the original concerns prompting this study was that an unknown number of engines were being rebuilt, reconditioned or remanufactured for sale in California and that their conformance with California certification requirements was unknown. Data were collected to determine the volume of engines remanufactured for sale in California. The information required to estimate the size of the rebuilding/reconditioning industry was supposed to be produced in a companion ARB study, unfortunately that study has only recently started, therefore no attempt has been made to estimate the size of that industry.

Table 5-1 presents a summary of the sales of major manufacturer new and remanufactured heavy-duty diesel engines in California in 1984 and 1985. As can be seen, the volume of remanufactured engines sold is miniscule in comparison to sales of new engines, on the order of 3 to 4 percent of total sales in each year. Conversations with the four largest engine manufacturers indicated that only two of them actually conducted the remanufacturing themselves: Caterpillar and Cummins. The remanufacturing of IH engines is conducted by a separate company, Springfield Remanufacturing Center. That company was created in 1977-1979 through a leveraged buyout from IH. Contacts with the Springfield Remanufacturing Center produced estimates of their California production volumes, as no detailed records on this category of remanufacturing is tracked by them. Remanufacturing of DDA equipment is conducted by three contractors under a licensing agreement. All of the rebuilding of California certified DDA engines is conducted by Pacific Diesel, a firm located in Seattle.

Additional checks of aftermarket remanufacturing indicated that several independent firms operate across the country. Production volumes for California engines appear to be quite small; however, little data were available to confirm this. Conversations with Korody-Colyer indicated that they used to remanufacture engines at the

TABLE 5-1

CALIFORNIA SALES OF NEW & REMANUFACTURED HD ENGINES FOR SELECTED MANUFACTURERS

	1984		1985	
	Remanufactured	New	Remanufactured	New
IH DT-466*	10	2643	20	2845
6.9L		11414		13768
DDA 8.2	34**	1510	36	2069
8.2T	25**	1672	59	1384
6L71TA	---	326	---	146
6V92TA	---	734	---	708
8V92TA	---	350	---	321
Caterpillar				
3208	285	719	336	1270
3406	8	580	5	1300
Cummins				
NTC	520	3744	408	4056
TOTAL	882	23692	864	27867

*Conversations with Springfield Remanufacturing Center indicated that they produce three categories of remanufactured engines: skeleton (short block); long block equivalent; and replacement (includes all components). The values included in this table are only for the replacement values. Estimates of the skeleton category were roughly three times the volume estimated for replacement engines.

**Pacific Diesel

of about 250 per year, California and federal. They remanufactured mostly DDA equipment and maintained an inventory of about 25 engines. In February of this year, they made a decision to get out of that business.

Manufacturers indicated that their remanufactured engines were required to certify to the same emission levels as when the engine was new and that no adverse emissions impact was caused by these engines. They also indicated that production volumes of federal engines were 8 to 10 times the levels of California engines.

In addition to collecting data on the number of remanufactured engines sold in California, the contract called for an estimate of the number of rebuilt and reconditioned engines sold or produced in California by model year. No statistics are available to quantify the sales or rebuilds conducted each year. Conversations with everyone contacted in this study indicated that the vast majority of rebuilds are conducted under contract to the owner of the engine. Generally, the engine is sent for remanufacturing at the end of its useful economic life and is traded in to reduce the cost of a replacement engine. As shown in Table 5-1, the number of remanufactured California engines reported is relatively small.

In the course of the contract, a method was developed to estimate the number of rebuilds occurring each year in California. That approach requires the following information:

- frequency distribution, for all California certified engines, of the number of engines by odometer reading and model year at 100,000 mile increments from 0 to 2 million miles in a particular calendar year;

- mileage accumulation rates for California vehicles as a function of age; the information employed in EMFAC7C was derived from the 1972 Census of Truck Transportation and Use Survey;

- the intervals between rebuilds collected in this study.

Using the above data sets, it would be possible to estimate the number of rebuilds occurring each model year. The information for the first two categories is either unavailable or out-of-date. This study produced the data for the third category. A contract to generate the data for the first two categories from the 1982 Truck Inventory and Use Survey was to be in place before the end of this effort. That contract was delayed, and the data necessary to support this analysis was unavailable; therefore, the number of rebuilds occurring in California each year was not produced.

5.3 MILEAGE BETWEEN REBUILDS

A substantial body of data on the mileage between rebuilds was collected from manufacturers, fleets and rebuild shops. With the exception of those few California models certified in the early 80's with exhaust-gas recirculation (EGR) systems, manufacturers could see no reason for a difference in the mileage accumulated between California and federal engines before rebuilds. For this reason, no data is presented on the differences on the mileage experience collected from California and federal, fleet and rebuild shops. Sierra reviewed the differences reported by these groups and found them to be conflicting and relatively small in comparison to the differences reported among the respondents.

Table 5-2 provides a summary of the mileage accumulated prior to first and second rebuilds for medium, heavy-duty and bus engines. Fleets consistently reported higher mileages before rebuilds than those of rebuild shops or most manufacturers. This was true for both California and federal fleets. The reason for the higher mileage

TABLE 5-2

SUMMARY OF REBUILD MILEAGE

FIRST REBUILD

Group Surveyed	Heavy	Coefficient of Variation	Medium	Coefficient of Variation	Bus	Coefficient of Variation
Fleet (Sample Size) (Survey #3)	431,488 (41)	24.5	219,333 (33)	53.5	250,000 (1)	----
Rebuild Shop (Sample Size) (Survey #4)	336,458 (48)	25.7	171,512 (43)	41.4	213,800 (25)	70.0
Manufacturer						
Caterpillar	500,000	----	6,000 hrs	----	6,000 hrs	----
Cummins	300,000	----	300,000	----	----	----
DDA	350,000	----	200,000	----	400,000	----
IH	----	----	200,000	----	200,000	----

SECOND REBUILD

Group Surveyed	Heavy	Coefficient of Variation	Medium	Coefficient of Variation	Bus	Coefficient of Variation
Fleet (Sample Size) (Survey #3)	336,429 (35)	36.4	171,731 (26)	67.0	200,000 (1)	----
Rebuild Shop (Sample Size) (Survey #4)	270,227 (44)	33.6	139,643 (42)	43.2	177,174 (23)	63.5
Manufacturer						
Caterpillar	450,000	----	6,000 hrs	----	6,000 hrs	----
Cummins	210,000	----	210,000	----	----	----
DDA	300,000	----	160,000	----	325,000	----
IH	----	----	----	----	----	----

levels experienced by fleets appears to be their emphasis on preventive maintenance. All of the fleets that we contacted in Survey #3 required maintenance checks at specified intervals. During these checks, mechanics are required to review, repair and note the status of high wear engine components as well as other equipment categories (e.g., chassis, electrical, brakes, etc.). Many of the firms maintain computerized reporting systems to track the performance of the engine, components and mechanics. Almost one half of the fleets used oil analysis programs to check for metal fillings and unexpectedly high wear rates.

Rebuild shops, Survey #4, reported lower average mileage intervals between rebuilds. We believe that this reflects their customers lack of maintenance sophistication. It may also reflect an older age distribution of the equipment that they service; however, no data was available to support this. Conversations with rebuild shops indicated that owner/operators are often careful about preventive maintenance checks and frequently request an oil analysis test.

Heavy-duty engines were reported by both rebuild shops and fleets to accumulate almost twice the mileage of medium-duty engines. This observation is consistent for the first and second rebuilds. We believe this is largely due to a difference in duty cycles. Surprisingly, the information provided by Cummins indicates no difference in mileage accumulation rates between these two classes of engines.

Only one response was received from the fleet survey (Survey #3) on bus mileage. The primary information sources for buses are either municipal transit departments or long distance bus companies. These groups were not heavily sampled in the survey. The rebuild shops, providing approximately 25 responses on bus questions, are a much stronger information source. There is little agreement between the fleet and manufacturer reports on buses. This is largely due to the fact that DDA sells to the heavy-heavy duty end of the market and I/H sells to the medium-heavy end of the market. The responses from the fleets did not distinguish between the bus equipment that they worked with, thus we could not correlate the responses. The important trend to be observed is that buses, in either category, had a lower mileage accumulation rate than heavy-duty engines, and that they experienced a reduction in mileage accumulated between the first and second rebuilds.

All of the respondents noted a reduction in the mileage accumulated between the first and second rebuilds. This reflects two facts: first, wear rates are not linear and knowledge of the actual rate of wear between the first and second rebuild is imperfect; second, the first rebuild is generally an in-frame, and it is not possible to check the dimensional tolerances for all of the components. Thus, experience and caution lead to a reduction in the mileage accumulated between each successive rebuild.

Manufacturer responses were generally consistent for both the first and second rebuild. Short-haul and line-haul trucks always received an in-frame rebuild the first time. However, bus engines were usually built out-of-frame (due to limited engine access). At the second rebuild, answers were consistent in claiming that line-haul engines received an out-of-frame rebuild, while both short-haul and bus engines are remanufactured at this point. Manufacturers uniformly indicated that the mileage between the first and second overhauls was about 15 to 20 percent lower than the mileage to first overhaul. As previously noted, Cummins was the only exception to this trend.

5.4 REBUILD FREQUENCY AND EXPECTED USEFUL LIFE

Data to answer questions about rebuild frequency and expected useful life were collected from the survey of rebuild shops. No data on this subject were collected from fleets because, in conversations with Mr. Hoffman and selected fleet managers, it became apparent that a frequent practice in the industry is to sell the equipment before it is beyond repair. Therefore, responses to these questions would be based on perception instead of experience. For this reason, the survey focused on rebuild shops for the data to these questions.

The rebuild shops conduct repair/rebuild work for a wide range of clients, including owner/operators and small to midsize fleets. As vehicles age, they are more likely to end up in the ownership of these groups than in large fleets. The rebuild shop questionnaire, Survey #4, specifically requested insight into their experience with the expected life of engines. Table 5-3 provides a listing of the question and the responses received.

Data are presented for California, federal and total responses. The average number of rebuilds that an engine will receive in its useful life is 4. The average mileage accumulated in a useful life is a shade over 1 million miles. The sample size for the identified California responses is too small to provide any statistical confidence in the results presented. Nevertheless, the information collected appears to be consistent across geographical boundaries. The sums of the California and federal tabulations do not equal those presented in the total category. The reason for this is that one category of the rebuild shop survey went to independent California and federal facilities and many of the respondents did not identify themselves. Thus, it was not possible to segregate their responses.

5.5 REBUILD COSTS

Questions on the costs of rebuilds were included in all of the surveys and a large body of data was collected. Data on the cost of injection equipment repairs were collected from ADS members (Survey #2); no data on engine rebuild costs were collected from them because of their limited exposure to engine repairs.

TABLE 5-3

REBUILD FREQUENCY AND EXPECTED USEFUL LIFE

	CALIFORNIA		FEDERAL		TOTAL	
	Number of Rebuilds	Miles (x 10^3)	Number of Rebuilds	Miles (x 10^3)	Number of Rebuilds	Miles (x 10^3)
Minimum	2	500	3	500	2	400
Maximum	5	2,000	6	2,000	6	2,000
Mean	3	1,056	4	1,043	4	1,012
Coefficient of Variation		38.6		36.4		36.6
Sample Size	11	11	24	22	41*	39*

Survey Question:

How many rebuilds will an average engine block receive before it is beyond repair and can you estimate the number of miles on the engine at that time?

Number of rebuilds ____________
Lifetime miles ____________

*The total values are greater than the sum of California and federal values because some of the respondents chose not to indicate the location of their business or the category of engines that they serviced (i.e., California versus federal).

Table 5-4 presents a summary of data collected from each of the survey participants on engine rebuild costs. Rebuild shops noted a higher average cost than fleets for heavy-duty engines. The high coefficient of variation for the fleet values makes it difficult to show a substantial difference between fleet and rebuild shop costs. We believe, however, that the cost of repairs should be higher for rebuild shops than for fleets. The high volume of rebuild work, combined with the advantages of in-house labor costs, should provide a cost advantage for fleets. One of the surprises of the site surveys, however, was that most small and midsize fleets conducted very few of the component repairs in-house. All they did was tear the engine down and send out components for tests and repairs. This came as a surprise and diminishes the in-house cost advantage cited above.

The average medium-duty costs are almost identical between fleet and rebuild shop responses. Again, the coefficient of variation for the fleet numbers makes it difficult to have any confidence in this conclusion.

Estimates of rebuild costs varied by manufacturer. Caterpillar, which sells a line of premium diesels, quoted the highest costs and the longest mileage interval. Cummins provided costs as a percent of new engine price. No data was provided distinguishing costs between either medium versus heavy or between California versus federal engines. In general, however, the information was consistent with that collected in the surveys.

The costs incurred at the second rebuild are substantially higher than those at the first. The second rebuild is almost always an out-of-frame, and the number of components serviced is much greater than for an in-frame rebuild. The next section in this chapter presents a

TABLE 5-4

REBUILD COST
($)

IN-FRAME

Group Surveyed	Heavy	Coefficient of Variation	Medium	Coefficient of Variation
Fleet (Sample Size) (Survey #3)	4,037 (42)	40.5	3,092 (27)	49.6
Rebuild Shop (Sample Size) (Survey #4)	4,623 (47)	29.3	3,086 (43)	30.0

Manufacturer

Caterpillar	4,500-5,500
Cummins	25-30% of initial cost
DDA	3,500
IH	4,000

OUT-OF-FRAME

Group Surveyed	Heavy	Coefficient of Variation	Medium	Coefficient of Variation
Fleet (Sample Size) (Survey #3)	6,176 (41)	38.8	4,508 (27)	42.6
Rebuild Shop (Sample Size) (Survey #4)	8,000 (47)	18.4	5,138 (42)	25.8

Manufacturer

Caterpillar	8,000-8,500
Cummins	50% of initial cost
DDA	5,000
IH	6,000

summary of the components serviced at both rebuilds and will give more insight into the causes of the cost difference noted. Rebuild shops appear to cost more at the second rebuild than for the fleets, however, the coefficient of variation for the fleets is so high that there can be no confidence in this finding. The data submitted by the manufacturers is consistent with that collected in the survey.

Sierra conducted a detailed review of the costs collected in the surveys to determine whether there were substantial differences between the costs of California and federal rebuilds. The small sample sizes combined with the large variation in the responses made it impossible to find any statistically significant differences. The manufacturers indicated, in conversations, that they saw no reason for a difference between California and federal engine rebuild costs. The only cause of a price difference should be an equipment difference. California and federal engines use, with very few exceptions, the same components. The components have different design specifications (e.g., injection timing, spray pattern, turbo sizing, etc.), but these specifications should not lead to an increase in cost for the rebuild for a California engine. The only engines that could be identified as having a higher rebuild cost are those Cummins engines employing mechanically variable timing (MVT). This system was introduced on California certified engines in 1984; it is estimated to add $750 to $1,000 to the cost of a rebuild.

The survey of rebuild shops (Survey #4) also requested data on the respondent's perception of the rebuild cost as a percentage of the cost of a new engine. Table 5-5 presents a summary of the responses. There is a clear cost advantage, under any of the options, to paying for a rebuild rather than a new engine. The relative cost of an in-frame rebuild is higher than noted by Cummins in its estimate of 25 - 30 percent. The same is true for the out-of-frame rebuild, where medium and heavy-duty is estimated by the rebuild shops to be 64 percent versus the 50 percent noted by Cummins. The variation in estimates is outlined by the high and low values; the range is quite

TABLE 5-5

REBUILD COST AS A PERCENTAGE OF NEW ENGINE PRICE
(Based on Survey of Rebuild Shops, Survey #4)

TOTAL

	Minimum	Maximum	Average	Sample Size
Heavy In-Frame	18	80	40	44
Heavy Out-of-Frame	25	95	64	44
Medium In-Frame	20	75	43	39
Medium Out-of-Frame	25	90	64	38

CALIFORNIA

	Minimum	Maximum	Average	Sample Size
Heavy In-Frame	30	80	48	13
Heavy Out-of-Frame	45	95	71	13
Medium In-Frame	26	75	50	11
Medium Out-of-Frame	60	90	75	10

FEDERAL

	Minimum	Maximum	Average	Sample Size
Heavy In-Frame	18	70	37	26
Heavy Out-of-Frame	35	80	61	26
Medium In-Frame	20	70	40	25
Medium Out-of-Frame	30	85	61	25

high given that manufacturers specify the components to be checked and the dimensional tolerances allowed for each type of rebuild.

To provide a sense of the sample sizes and the range in responses, Table 5-5 also presents the data collected from California and federal rebuild shops separately. Again, the range in responses and the small sample sizes make it difficult to discern a difference between the two groups.

5.6 COMPONENT SERVICING PRACTICES

A large portion of each survey was devoted to determining the components serviced during in-frame and out-of-frame rebuilds. Conversations with manufacturers indicated that practices vary depending on the type of engine, the type of service that the engine experiences, and the component tolerances. This information is published in a rebuild repair manual for each engine family. The use of these manuals is standard operating procedure at all rebuild facilities.

Tables 5-6 and 5-7 present a summary of the data collected from the fleet survey on the in-frame and out-of-frame rebuilds, respectively. Tables 5-8 and 5-9 present the same information for the data collected from the rebuild shops. The questionnaires only asked for information on the servicing of components that we judged to affect emissions, therefore a large portion of the components regularly serviced during the rebuild process are not listed.

The number of components not serviced during in-frame rebuilds is generally higher than for out-of-frame rebuilds, the responses being consistent for both fleets and rebuild shops. The striking feature of these tables is that all of the components appear to be serviced, regardless of rebuild type or respondent. This conflicts with information provided by the manufacturers. All manufacturers

TABLE 5-6

SUMMARY OF REBUILD
COMPONENT SERVICING PRACTICES
IN-FRAME
FLEET SURVEY (Survey #3)
(% DISTRIBUTION)

	Not Serviced	Original Part Rebuilt	Replaced With Rebuilt Parts	Replaced With New OEM Parts	Replaced With New Aftermarket Parts	Sample Size
Piston Rings	2	0	0	93	5	42
Cylinder Liners	7	0	0	88	5	42
Pistons	7	2	2	83	5	42
Cylinder Heads	0	45	40	10	5	42
Fuel Injectors	0	43	38	14	5	42
Injection Pumps	5	50	29	12	5	42
Governors or Fuel Delay Mechanisms	9	50	24	15	3	34
Turbochargers	2	38	43	12	5	42
Aftercoolers	8	56	26	8	3	39
Roots Blowers	4	50	27	15	4	26
Rocker Arms	12	39	27	20	2	41

TABLE 5-7

SUMMARY OF REBUILD
SERVICING PRACTICES
OUT-OF-FRAME
FLEET SURVEY (Survey #3)
(% DISTRIBUTION)

	Not Serviced	Original Part Rebuilt	Replaced With Rebuilt Parts	Replaced With New OEM Parts	Replaced With New Aftermarket Parts	Sample Size
Piston Rings	0	0	0	95	5	42
Cylinder Liners	0	0	0	95	5	42
Pistons	0	0	2	93	5	42
Cylinder Heads	0	40	43	12	5	42
Fuel Injectors	0	43	45	10	2	42
Injection Pumps	2	50	36	10	2	42
Turbochargers	0	48	35	15	2	40
Aftercoolers	3	59	26	10	3	39
Roots Blowers	4	46	31	15	4	26
Rocker Arms	2	50	28	18	2	40

TABLE 5-8

SUMMARY OF REBUILD
COMPONENT SERVICING PRACTICES
IN-FRAME
REBUILD SHOP SURVEY (Survey #4)
(% DISTRIBUTION)

	Not Serviced	Original Part Rebuilt	Replaced With Rebuilt Parts	Replaced With New OEM Parts	Replaced With New Aftermarket Parts	Sample Size
Piston Rings	0	0	0	100	0	47
Cylinder Liners	0	0	2	98	0	47
Pistons	0	0	2	98	0	47
Cylinder Heads	0	17	68	15	0	47
Fuel Injectors	0	11	72	17	0	47
Injection Pumps	18	24	53	4	0	45
Governors or Fuel Delay Mechanisms	9	46	30	15	0	46
Turbochargers	2	13	78	7	0	45
Aftercoolers	18	33	27	22	0	45
Roots Blowers	2	35	38	7	0	40
Rocker Arms	13	22	41	24	0	46

TABLE 5-9

SUMMARY OF REBUILD BEHAVIOR
COMPONENT SERVICING
OUT-OF-FRAME
REBUILD SHOP SURVEY (Survey #4)
(% DISTRIBUTION)

	Not Serviced	Original Part Rebuilt	Replaced With Rebuilt Parts	Replaced With New OEM Parts	Replaced With New Aftermarket Parts	Sample Size
Piston Rings	0	0	0	100	0	47
Cylinder Liners	0	0	2	98	0	47
Pistons	0	0	2	98	0	47
Cylinder Heads	0	19	64	17	0	47
Fuel Injectors	0	9	77	15	0	47
Injection Pumps	0	23	66	11	0	47
Turbochargers	0	11	81	9	0	47
Aftercoolers	0	39	39	20	2	44
Roots Blowers	0	38	51	10	0	39
Rocker Arms	0	20	50	30	0	46

uniformly claimed that the injection pump and governor were not rebuilt for the first or in-frame rebuild. All others, except DDA, also claimed that turbochargers, aftercoolers, rocker arms and camshafts were not replaced/rebuilt at the first rebuild. The survey data indicate a high level of either replacement or rebuilding of all of those parts.

The responses also show a very low reliance on aftermarket parts and a commensurate use of either new OEM or rebuilt parts. The low level of aftermarket parts usage is significant because at the outset of the study these parts were suspected of increasing emission levels. Only one of the rebuild shop respondents admitted to the use of aftermarket parts. This is not completely surprising in that many of the shops are in some way affiliated with one or more of the engine manufacturers. Nevertheless, we were surprised that, out of 44 respondents, only one admitted the use of aftermarket parts. The fleet use of aftermarket parts is less surprising in that their knowledge of component manufacturers may lead them to the most cost effective source, particularly when the same component manufacturer is supplying both the aftermarket and the OEM. A detailed discussion of the quality and use of aftermarket parts will be presented in the next section.

The available data on the types of practices employed in the rebuilding industry indicated that there is no substantial difference between the practices employed by rebuilders in California versus those across the rest of the country. The survey data sample sizes, when subdivided within each of the survey categories, dropped substantially and made a valid comparison of California versus non-California prctices impractical across the range of categories identified in Tables 5-6 through 5-9.

Conversations with manufacturers indicated that the same procedures were recommended for use by rebuilders across the country. Follow-up telephone conversations confirmed this trend. Some dealers in the east indicated parts problems for California engines but indicated they could order the necessary parts when needed.

Tables 5-6 through 5-9 indicate that differences in rebuilding practices are more likely to occur based on the type of operation - fleet versus dealer - than California versus 49-state location. Site visits and telephone contacts indicate that another variant on the procedure depends on the size of the fleet operation. The smaller operations (e.g., less than 200 vehicles) frequently subcontract out the types of repairs required rather than conducting them in-house. The larger operations can afford to conduct more of the work in-house and exercise greater control on the type of procedures they want conducted.

It is <u>not possible to estimate</u> the percentage of rebuilds following the repair practices discussed in this section. Many factors preclude this estimate:

- the range of practices;
- the range of repairs;
- the differences among manufacturer equipment and recommendations for servicing at different mileage intervals;
- the lack of information on the cumulative distribution of engines by odometer reading in service in California;
- the lack of detailed information on differences in repair practices followed by rebuilders on engine lines by manufacturer.

Most, if not all, of those surveyed repaired more than one manufacturer's equipment. This made it impossible to collect servicing behavior on each type of engine supported at the rebuild shop. The burden of the information request would have severely reduced the response rate.

5.7 USE OF AFTERMARKET PARTS

Because of the concern about the poor quality of aftermarket dimensional tolerances, the attractiveness of their low costs relative to OEM parts, and their potential impact on emissions, a substantial effort was undertaken to learn more about this portion of the rebuild industry. As discussed in Chapter 3, numerous aftermarket parts (AMP's) suppliers were contacted for information about the specifications of their parts and their quality control procedures. Many rebuild shops were also contacted to collect data on the prices charged for OEM and aftermarket parts and purchasing patterns.

Conversations with the aftermarket suppliers indicated that they concentrated their business on high mortality parts. No data, outside of that collected in the survey, is available to quantify the marketshare for this business; however, one of the suppliers, Korody-Colyer, estimated that OEM's have approximately 85 - 90 percent of the market. Korody-Colyer estimated that it has approximately 5 of the remaining 10 to 15 percent of the remaining market. The estimate of a 10 to 15 percent market share for aftermarket parts is roughly double to triple the maximum observed in the survey. Manufacturers indicated that AMP's were a force in the parts business but declined to estimate their market share.

Assuming that the above information is correct for a ballpark estimate of 5 to 15 percent, the next step in this analysis was to evaluate the incentives for the use of aftermarket parts. The primary incentive stimulating the use of AMP's is that they are supposed to be cheaper than OEM parts. Sierra conducted a telephone survey of rebuild shops to identify the prices charged for identical emission critical parts supplied by OEM's and the aftermarket. Part numbers for selected emission critical parts were obtained from the manufacturers and are listed in Appendix B.

Table 5-10 contains a summary of the prices charged for selected parts in California rebuild shops. Two categories of prices are displayed: new and with exchange. As would be expected, parts accompanied with an exchange are substantially cheaper than new parts. Generally the prices charged for AMP's are cheaper than for OEM parts; however, this is not always the case. The prices charged for Cummins parts are either equal to or less expensive than the AMP's. The information contained in this table is the result of random telephone calls to rebuild shops, rather than a rigorous statistical sampling. Therefore, no firm conclusions about the price relationship on these parts can be drawn. The data do, however, cast doubt on the conventional wisdom that AMP's are always cheaper than OEM's.

The most serious concern about AMP's is that the specifications governing their production are less stringent than those of the OEM's. The less rigorous specifications are supposed to lead to lower quality parts, with either higher dimensional variations or less durable materials. In either case, these variations from OEM specs are supposed to lead to an increase in emissions.

As outlined in Chapter 3, Sierra contacted several AMP suppliers and spoke to their engineers about the specifications used in the production of their parts. All of the firms indicated that they used the same specifications as set by OEM's for their parts. These specifications covered both dimensional tolerances and materials composition. They also indicated that they frequently purchased parts from the same suppliers that produced parts for the OEM's. Table 5-11 contains a listing of OEM part suppliers producing parts for sale in the aftermarket. This is not an exhaustive list of all producers making emission critical parts but an indication that the practice is common. The range of parts suppliers is evidently quite broad and includes both domestic and overseas production facilities. A pattern much the same is seen in the sourcing of OEM components.

TABLE 5-10

COMPARISON OF OEM AND AFTERMARKET
EMISSION CRITICAL PART PRICES
FOR
SELECTED ENGINES

			PRICE ($)			
			OEM		AFTERMARKET	
Manufacturer	Engine	Part	New	with Exchange	New	with Exchange
DDA	8.2 NA	Injectors	144.10	45.33	NA	NA
	8.2 Turbo	Injectors	144.10	45.33	NA	NA
	6V-92T	Injectors	187.52	47.27	NA	40.63
		Blower	1,775.58	433.38	NA	375.00
		Turbochargers	1,137.22	NA	1,080.31	714.00
CUMMINS	NTC400	Injectors	257.07	29.40	NA	29.04
		Pistons	105.72	?	NA	66.74-84.32
		Camshaft	574.79	NA	574.79	NA
		Variable Timing	136.92	NA	136.92	NA
		Turbocharger	1,307.57	356.39	NA	379.00

TABLE 5-11

OEM SUPPLIERS THAT PRODUCE PARTS
FOR SALE IN THE AFTERMARKET

Part	Manufacturer
Fuel Nozzles	Stanadyne
Rings	Perfect Circle Ryken Wellworthy
Camshaft	Dana
Aftercooler	Modene Air Research
Pistons	Zalhner Koppers
Air-to-Air Intercooler	Blackstone

The only issue that we could identify that might affect the quality of AMP's is the quality control procedures used to check the dimensional tolerances of the parts received from the manufacturer. Some of the AMP suppliers indicated that they sampled all of the parts manufactured internally or purchased from the outside and checked the dimensional specifications on them before they were offered for sale. Through this process, parts identified as being beyond acceptable tolerances were rejected. Concerns about violating these tolerances are sufficient to cause many of the rebuild shops to "mic" all parts before they are used, regardless of whether they are supplied by OEM's or AMP's.

Based on the information collected in this study, it appears that aftermarket part use is not extensive, with an identified upper limit of 15 percent. The specifications set for the production of the parts appear to be the same as those employed by the OEM's. In addition, many of the parts supplied in the aftermarket are produced by the same manufacturers supplying the OEM's. The prices charged for AMP's are not consistently cheaper than those of OEM's and are in some cases higher. This would support the theory that there is little difference in quality between the two sources. The concern about variations in dimensional specifications is sufficient to cause many rebuilding facilities to check the specs on all parts regardless of the source. All of the above information leads us to conclude that the use of AMP's is not a source of concern from an environmental perspective.

5.8 FREQUENCY OF UPRATING

Uprating refers to the practice of rebuilding an older engine to a newer specification, usually to increase the horsepower and/or its efficiency. Many options are available for uprating, some can result in a benefit to emissions, others may result in rebuilding to a federal specification and an increase in emissions.

Data was collected from both the fleets (Survey #3) and from the rebuild shops (Survey #4) on the frequency at which they uprated engines. The results are listed below.

FREQUENCY OF UPRATING
(PERCENT)
(Survey #'s 3 & 4)

	REBUILD SHOP			FLEET		
	CALIF	FEDERAL	TOTAL	CALIF	FEDERAL	TOTAL
MINIMUM	3	2	2	2	1	1
MAXIMUM	100	100	100	100	100	100
MEAN	29	21	23	48	35	41
COEFFICIENT OF VARIATION	117.5	119.4	117.6	96.3	123.5	105.7
SAMPLE SIZE	8	23	31	7	10	17

There are wide variations in the frequency of uprating reported by the respondents. Obviously, some of the shops and the fleets follow uprating as a common practice as indicated by the 100 percent values included in all of the certification categories listed above. Fleets appear to uprate more frequently than rebuild shops. The variation in the responses received, however, does not support any firm conclusions on these comparisons.

Conversations with rebuild shops and fleets indicate that it is largely a matter of equipment requirements. Uprating is a cost effective method of increasing the horsepower of the engine without having to purchase a new one. It is likely to increase the cost of the rebuild as more components may be required to be replaced and it can occur in either an in-frame or out-of-frame, depending on the equipment changes required.

All of the fleets contacted through follow-up phone calls indicated that they only uprated to California specifications. Conversations with rebuild shops indicated that occasionally they were asked to change the spec of a California engine to that of a federal engine. although this was an uncommon occurrence. One dealer for Caterpillar indicated that the manufacturer maintained careful computer records on the certification of the engine, and that Cat dealers were not allowed to rebuild the engine to a federal specification without manufacturer approval. He also indicated that a common practice to avoid conflict with the manufacturer was for a driver to take receipt of the new engine outside of California. The basis for the manufacturer's check is the original certification of the engine.

Based on the data collected, it is difficult to see a significant adverse emissions impact associated with uprating. Uprating can have either a beneficial or an adverse environmental impact. Uprating is not an uncommon occurrence, as evidenced by the 23 and 41 percent average rates indicated in the survey. The rate of incorrect upratings is unknown, but the information collected indicates that it is not a common practice, and that some manufacturers try to constrain the practice.

5.9 WARRANTY COVERAGE

The data on warranty coverage was collected from the engine manufacturers and selected conversations with rebuild shops. A range of policies is available for new engines and depends on the type of coverage and amount of money that the purchaser wants to spend. Typical coverages for base medium-heavy and heavy-heavy engines are 24 months or 100,000 miles, whichever comes first. Options are available to extend coverage to 200,000 or 300,000 miles.

Rebuilt medium-heavy and heavy-heavy engines generally receive a 6 month or 50,000 mile policy. Variations on this policy are much more limited; a manufacturer may offer a 6-month policy with unlimited mileage or a dealer will extend the basic 100,000 mile policy to one year. In general, manufacturers do not support a policy beyond a 6-month period; any extension is supported by the dealer as a way of gaining market share. A prerequisite to obtaining the manufacturer warranty at rebuild is the exclusive use of OEM parts, either new or in some cases rebuilt, in the rebuild.

5.10 QUALITY CONTROL PROCEDURES

Another issue of concern related to the rebuild process is whether any quality control practices are used to check a performance (e.g., fuel consumption or emissions) attribute of a rebuilt engine. Questionnaires to the fleets and the rebuild shops requested information on the following subjects:

- gaseous emission measurements;
- full power curve check;
- power or torque checks at selected points; and
- fuel consumption measurement.

The gaseous emissions measurement questions can be divided into two segments: those that measure smoke, and those that measure HC, CO, and NOx. Only four respondents from the combined fleet and rebuild shop surveys indicated any measurement of the three regulated pollutants. Follow-up telephone calls found that one response was a mistake, and that a second was only for gasoline equipment; we have been unable to contact the third and fourth respondents for more insight.

Measurements of smoke were more numerous, with 22 percent of the rebuild shops providing positive responses. Less than 10 percent of the fleet respondents indicated smoke measurements. The mix of respondents from rebuild shops measuring smoke was evenly split between California and federal shops; only one of the fleets measuring smoke was located in California.

A summary of the responses to the remaining quality control measures is presented below.

ENGINE MEASUREMENTS AT THE COMPLETION OF OVERHAUL
(PERCENT OF RESPONDENTS INDICATING YES)

	FLEET (Survey #3)			REBUILD SHOP (Survey #4)		
	CALIF	FEDERAL	TOTAL	CALIF	FEDERAL	TOTAL
FULL POWER CURVE	62	56	58	65	63	64
(Sample Size)	(13)	(27)	(40)	(20)	(19)	(39)
CHECK POWER OR TORQUE AT SELECTED POINTS	54	67	63	63	63	63
(Sample Size)	(13)	(27)	(40)	(19)	(19)	(38)
FUEL CONSUMPTION MEASUREMENT	23	27	26	55	58	56
(Sample Size)	(13)	(26)	(39)	(20)	(19)	(39)

The responses provided to the above questions are very consistent. With the exception of fleet measurements of fuel consumption, both in and out of California, all of the respondents indicated that power measurements are quite common. Fuel consumption measurements are also common in rebuild shops. Several of the respondents indicated that the fuel consumption measurements are performed only when requested, and not on a regular basis.

5.11 FUEL INJECTION EQUIPMENT

A large body of information was collected on fuel injection system tampering rates and rebuild practices. A separate questionnaire was sent to ADS members (Survey #2); questions on injection system modifications were also included in the fleet and rebuild shop surveys. Several problems were encountered when trying to analyze the responses. The response rate from the ADS members, while overall quite high, was extremely low for California, with only one useable California response received. Many of the repair shops and fleets are not equipped to work on injection equipment, and the sample size of those that are was disappointing. The remainder of this section is organized to first provide a summary of the ADS responses and then the information collected from the fleets and rebuild shops.

Most of the ADS respondents had no idea of the mileage accumulated on the equipment received for repairs. Only 20 percent of the respondents provided estimates to this question. A summary is provided below.

INJECTION EQUIPMENT REBUILD MILEAGE
(Survey #2)

	PUMPS	INJECTORS	TURBOCHARGERS	GOVERNORS
AVERAGE MILES BEFORE 1st REBUILD (000 MI)	201	123	226	229
(Sample Size)	(8)	(7)	(5)	(5)
COEFFICIENT OF VARIATION	48.9	32.1	34.6	37.4
AVERAGE MILES BETWEEN 1st AND 2nd REBUILD (000 MI)	175	90	213	183
(Sample Size)	(6)	(5)	(4)	(3)
COEFFICIENT OF VARIATION	43.3	46.5	44.4	15.8

The largest number of respondents providing data for any of the above categories was eight, therefore the large variations shown are not surprising. The low mileages estimated for the first rebuild conflict with information supplied by the engine manufacturers. They uniformly claimed that the injection pump and governor were not rebuilt for the first or in-frame rebuild. All others except DDA also claimed that turbochargers were not rebuilt at the first rebuild. The above mileages are substantially lower than the averages observed for the first rebuild of either heavy or medium duty engines for any of the groups surveyed. If the survey responses are at all representative, then it would appear that most of the equipment is rebuilt at the first rebuild. The data presented in the discussion of component servicing patterns also support this conclusion.

Use of aftermarket parts among ADS members was substantially higher than observed in any of the other surveys. Approximately 35 percent of the respondents indicated that they used a mixture of OEM and aftermarket parts. Responses to questions about quality of OEM versus AMP's fell into two categories, either no difference or a substantial difference. Several handwritten comments indicated that the quality of AMP's was variable and depended on the part and the manufacturer. This largely echoes what we learned about AMP's.

A high response was received to the question on overhaul costs of components; a summary is presented below.

COMPONENT REPAIR COSTS
(Survey #2)

	AVERAGE COST ($)	COEFFICIENT OF VARIATION	SAMPLE SIZE
INJECTION PUMPS	483.7	41.9	31
INJECTORS	26.8	27.9	33
TURBOCHARGERS	298.3	28.4	29
GOVERNORS	256.2	57.2	20

Many of the responses contained ranges of cost estimates and indicated that cost was dependent on the manufacturer. The high coefficient of variation for the injection pump rebuild cost reflects that range. Injector rebuild prices were much more consistent as were the prices for the turbochargers. A much smaller number of responses were received for the governor cost and the variation in those responses was substantially higher. Comments indicated that the differences between California and federal pumps are accommodated through changes in pump settings, and that few pumps require different parts.

The response rate on injection system modifications was only about 35 percent. Overall, 22 percent of the equipment they worked on had received some kind of modification, the observed rate ranged between 2 and 75 percent. The most common modifications noted were an increase in fuel rate above the manufacturer specifications and throttle delay disconnect. Comments indicated that customers often increased the fuel settings for more power. A more detailed discussion on the causes of these modifications and the rates observed in the data is presented in Chapter 6.

5.12 SPEC PLATE REMOVAL

During the course of the contract a question occurred about the frequency of which specification plates were removed from engines. The spec plate provides the repair/rebuild shop information on the engine family, date of delivery, advertised horsepower, fuel rate, and injection timing data. The removal of these plates, which are often aluminum strips riveted to the side of the engine, is a concern for repair and for emissions enforcement purposes.

A question was included in the survey of the rebuild shops about the percentage of engines they observed without these plates. The average response was 23 percent, but a wide range was noted, from 1 to 90 percent. The rate experienced in California shops was consistent with those observed in non-California shops, and the variation in the responses was just as large.

6. EMISSIONS IMPACT DUE TO IMPROPER REBUILD

6.1 OVERVIEW

The calculation of emission impacts associated with improper rebuilds is particularly difficult because there is little test data available on the emissions effects of component substitution during rebuild, and little data to quantify the rate of occurrence of usage of incorrectly specified parts during the rebuild. As a result, only a bounding analysis can be performed to estimate the potential range of emission impacts from rebuilding. It is necessary to make several assumptions in deriving this estimate, and the methods and assumptions used to develop the estimate are described below.

In Section 4 of this report, a detailed list of emission critical components was specified and the types of incorrect rebuilds of these components were identified. For each component and possible type of incorrect rebuild, an emission impact estimate is required. We have estimated these impacts through a combination of engineering analyses, discussions with manufacturer's technical staffs and comparisons of certification data from different model years or California versus Federal specification engine emissions. This is described in Section 6.3.

The impact of improper rebuilding on fleetwide emissions depends on the frequency of each incorrect rebuild type and its associated emission impact. The rates of occurrence were estimated from the questionnaire survey responses in combination with telephone follow-up surveys and some qualitative estimates of knowledgeable field personnel. The development of scenarios that bound the rate of occurrence of incorrect rebuild types is discussed in Section 6.4.

Section 6.5 integrates data from Sections 6.3 and 6.4 to derive the net emission impact of incorrect rebuild for each truck class.

Section 6.5 converts the estimates of the emission impacts into tons/day estimates for the Base and High Scenarios.

6.2 ESTIMATING EMISSIONS EFFECTS OF INCORRECT REBUILD

We have estimated emissions impacts as percentage increases over baseline emissions. The baseline emissions of a correctly rebuilt engine are expected to be equal to that of a new engine; limited data from the manufacturers on remanufactured engines supports this view. Rather than providing unreliable point estimates, we have estimated a range of emissions impacts based on different estimates of the rate of occurrence of incorrect rebuilds.

The increases have been classified into three ranges. Minor impact is associated with emission increases of 0 to 30 percent over baseline. It should be noted that these impacts are in the range of normal production variability between engines. However, the production variability of engines is plus or minus 30 percent (standard derivation from the mean), whereas the impacts associated with all incorrect rebuilds are usually all positive (increase) in emissions. Moderate impact is associated with emission increases of greater than 30, up to 100 percent over baseline, or two to three times normal variability. High impact is associated with emission increases of over 100 percent. Given the nature of diesel engines, few incorrect rebuild types result in such large emission impacts.

Since these percentage emission increases are measured from a baseline, the question of baseline emissions for individual model years must be resolved. As mentioned previously, diesel engines prior to the 1977 model year emitted at essentially uncontrolled levels, which were below applicable standards in that period. Our analysis assumes that those levels are representative of the highest emission levels that can arise from an improper rebuild, with the exception of one or two types of incorrect adjustment, as explained below.

Emission factors for HC and NOx emissions for new engines are provided in Table 6-1. CO emissions from diesel engines are very low and not of concern for this analysis.

Our emission model assumes that a correctly rebuilt engine will emit at levels close to the intercept (0-mile) values of the emission factors shown in Table 6-1. Emission factors for the entire 1977-1983 period are very similar, though there is a small (15 percent) reduction in NOx emission factors for the 1980-1983 period in comparison to the 1977-1979 period. Our measures of the emissions impact of incorrect rebuilds are more crude than that change; hence the incremental emissions impact in percentages are considered to be applicable to the entire 1977-1983 period. There is little experience with rebuilding 1984+ engines as of yet, and a simple methodology for estimating emissions impact for these engines is provided at the end of this section.

6.3 EMISSIONS EFFECTS OF INCORRECT REBUILD BY COMPONENT

As explained in Section 4, each component can be substituted by a functionally equivalent component that may be either calibrated to 49-state specifications as distinct from California specifications, or may be a component of an older design type that does not incorporate some of the advanced design features for emission controls. For each substitution type, we have estimated the percentage increase over baseline emissions.

The component specific emission impacts described below are applicable to 1977-1983 engines, both medium duty and heavy duty. In general, we have tried to provide averages across engine models, but make/model specific impact is estimated where required.

The fuel injection pump usually meters the fuel and incorporates the throttle and governor control for all engines except those

TABLE 6-1

EMISSION FACTORS FOR CALIFORNIA HDD
ENGINES - G/BHP-HR
(Transient test procedure)

	HC	NOx
pre-1977	1.23 + 0.002m*	8.5 + 0.06m
1977 - 1979	0.765 + 0.003m	7.15
1980 - 1983	0.880 + 0.003m	6.10
1984 - 1986	0.800 + 0.006m	4.80 + 0.02m

* m = 10^4 miles.

Source: Review and Critique of Current Heavy-Duty Truck Emission Factors, Mobile Source Emission Analysis for California, prepared for CARB by EEA and Sierra Research, June 1985.

manufactured by DDA. It is possible to substitute a 49-state pump for a California specification pump, creating some mismatch between available air and fuel. This can, in general, result in minor emission impacts for NOx, HC and particulate. However, wrong calibration or tampering of the pumps' full load fuel stop or governed maximum speed can lead to moderate or high emission increases of HC and particulate. (High emission impacts can result from excessive fueling in Cummins engines.) The miscalibration of injection pumps is also a common form of tampering that can occur during routine maintenance, as opposed to rebuild.

A variety of <u>injectors</u> are available for each engine with different stroke, flow rates and spray tips. Use of an older style high sac volume injector (possibly from non-OEM suppliers) can increase HC emissions by 100-150 percent - i.e., from 0.7 or 0.8 g/BHP-hr to 1.5 - 1.6 g/BHP-hr. Use of an incorrect spray tip for a particular engine can result in spray impingement on combustion chamber walls, leading to moderate increases in emission of HC and particulate. Of course, if a higher flow rate injector is combined with the right piston, turbocharger and pump, it can lead to a higher horsepower engine with no increase in emissions.

<u>Injection timing</u> can be varied by changing camshaft drive gear position or by using a different camshaft. Camshafts are usually replaced only in an out-of-frame rebuild, but changing an engine's injection timing during rebuild is not difficult. Advancing the timing within reasonable bounds results in a 10 percent increase in NOx but may decrease HC/particulate. Advancing time provides benefits in fuel economy, and may occur to a limited extent during rebuild. Retarding timing has the opposite effect, i.e., NOx emissions and fuel economy decrease, but HC/particulate emissions may increase. There is little incentive to retard timing and we do not believe this occurs except when there is an error in the rebuild. Using the Federal instead of the California camshaft may result in minor increases in all three emissions as both injection timing and injection period may

change. In addition, mechanically variable timing (MVT) has been adopted in most Cummins California specification engines starting in 1984. Since this item costs around $1,000, its removal may be advantageous economically. NOx, HC and particulate emissions may rise 15 to 20 percent as a result of removal of the MVT.

The use of a different turbocharger will affect air flow, and lead to some mismatch of fuel and air quality. The mismatch cannot be too severe as driveability will suffer, but the lack of adequate air may result in a 10-15 percent increase in HC/particulate emissions for certain types of mismatch.

The elimination of the aftercooler as a cost saving measure can result in a 50 percent increase in NOx emissions. Aftercoolers are used in most heavy-heavy duty California engines since 1984, but have the advantage of decreasing fuel consumption as well. A more common lack of service during rebuild is likely to result in NOx emission increases of only 10-15 percent. The effect of either removal or lack of service for this component has a minimal effect (about 5 percent) on HC/particulate emissions.

Finally, transient air-fuel ratio controllers (called smoke-puff limiters) can be eliminated or maladjusted during rebuild. This can also be done during routine maintenance. This adjustment increases HC and particulate emissions only during accelerations, over the entire driving cycle, the net effect on emissions is in the 10 percent range.

All of the percentages discussed above and summarized in Table 6-2 are relative to the baseline of new 1977-1983 engines. Starting in 1984, California engine's NOx emissions have declined further. This has been accomplished principally through the use of aftercoolers, reduced compression ratios and optimized injection timing (e.g., use of mechanically variable timing). Since the effects of aftercoolers and reduced compression ratios will be still viable with other types of maladjustments, it is assumed that the same percentage increases

TABLE 6-2

MAXIMUM EMISSION EFFECTS OF INCORRECT REBUILD

COMPONENT	0 - 30	30 - 100	100+
INJECTION PUMP			
- 49-STATE INSTEAD OF CALIFORNIA	HC/PARTICULATE/NOX		
- INCORRECT CALIBRATION (OVERFUELING)		HC/PARTICULATE	HC/PARTICULATE (SOME ENGINES)*
INJECTOR			
- HIGH SAC VOLUME DESIGN			HC/PARTICULATE
- WRONG SPRAY TIP	HC/PARTICULATE		
TIMING			
- 49-STATE CAMSHAFT	HC/PARTICULATE/NOX		
- ADVANCED	NOX		
- RETARDED	HC/PARTICULATE		
- MVT REMOVED*	HC/PARTICULATE/NOX		
INCORRECT TURBOCHARGER	HC/PARTICULATE		
AFTERCOOLER			
- REMOVED	HC/PARTICULATE	NOX	
- LACK OF SERVICE	NOX		
DISCONNECT/MALADJUST THROTTLE DELAY	HC/PARTICULATE		

*Cummins.

attributed to incorrect rebuild are still viable for 1984+ engines. This assumption, however, must be viewed as tentative until additional data on the rebuilds of late model engines become available.

6.4 DEVELOPMENT OF SCENARIOS BOUNDING THE RATE OF OCCURRENCE OF INCORRECT REBUILD TYPES

In order to translate the emission impacts of individual improper rebuild categories, identified in Table 6-2, into fleet average emission impacts or "offsets" it is necessary to estimate the percentage of vehicles receiving each of the improper rebuilds. The range of responses and information collected in the surveys dictated that no single value could correctly quantify the rate of occurrence for each of the improper rebuild categories. Therefore an approach was developed to bound the range of occurrence through scenarios. Several problems were encountered in the development of those scenarios; these were due in part to:

- the surveys not requesting information on the rate of occurrence of all incorrect rebuild types;
- the response rate from California shops in the ADS survey being quite low and providing little insight;
- the variability in the responses to some of the questions being high and sensitive to how the data were sorted (e.g., California dealers that worked on fuel injection systems versus those that did not).

The methodology used to overcome these problems and produce estimates of the rate of occurrence for each of the categories used a mixture of quantitative and qualitative methods. The following guidelines were used in the preparation of the scenarios:

- All estimates of the rate of occurrence "erred" to the high side to maximize the emission impacts. This approach was prompted by the relatively benign emission impacts associated with most types of incorrect rebuild identified in Table 6-3. If this approach does not generate substantial emission impacts then it will demonstrate that the rebuilding process is not a problem area.

- Whenever data were available for the California experience to be distinguished from the 49 state experience, the results of the California data were employed if the sample size was sufficient.
- An extensive telephone survey was conducted to quantify the rates of occurrence of rebuild types not addressed in the surveys. That survey focused exclusively on ADS members and dealers located in California.

The survey data from the fleets were not used in the development of the scenarios. Generally, fleets follow manufacturer guidelines and often implement their own programs to reduce driver tampering with fuel injection systems. The low rate of occurrence of incorrect rebuild types associated with fleets conflicts with the above guideline to maximize the emission impact; therefore, the fleet data were not employed.

The data from the surveys were sorted into the following categories:

- All Dealers
- California Dealers
- California Dealers that service injection equipment
- Dealers that service injection equipment

- All ADS Members
- California ADS Members

A qualitative process was used in developing the bounds of the three scenarios from the above data and augmenting it with the telephone survey results. Generally, the base case was generated from a review of the average values from each of the above categories. The high

TABLE 6-3

THREE SCENARIOS BOUNDING THE RANGE OF OCCURRENCE OF IMPROPER MAINTENANCE AND REBUILDING PROCEDURES
(% Occurrence)

INCORRECT REBUILD TYPE	BASE	SCENARIOS LOW	HIGH
49-STATE INSTEAD OF CALIFORNIA INJECTION PUMP	1	0	5
USE OF HIGH SAC VOLUME INJECTOR	1	0	2
WRONG INJECTION SPRAY TIP	1	0	2
49-STATE INSTEAD OF CALIFORNIA CAMSHAFT	1	0	5
INCORRECT INJECTION TIMING			
- ADVANCED	15	5	35
- RETARDED	5	1	10
49 STATE INSTEAD OF CALIFORNIA MVT FOR CUMMINS ENGINES	1	0	2
INCORRECT TURBOCHARGER	10	1	30
AFTERCOOLER REMOVED OR NOT SERVICED PROPERLY	5	1	15
DASHPOT OR THROTTLE DELAY DISCONNECTED	35	5	50
INCORRECT INJECTION PUMP CALIBRATION	30	5	50

case was developed from an average of the upper bound of the responses and the low case from an average of the lower bound responses. A listing of the information sources and quantitative/qualitative values used in developing the scenarios for each of the incorrect rebuilds in Table 6-3 follows.

<u>49 State Instead of California Injection Pump</u>

Based on information collected in the telephone interviews it is apparent that the rate of occurrence for this category is extremely low, on the order of one percent. Following the guidelines specified for constructing the scenarios a somewhat arbitrary decision was made to set the average rate of occurrence at one percent and the low bound at zero percent. The high bound was set at 5 percent and reflects a decision to temper or reduce the highest reported value of 10-15 percent because only a portion of the fleet, older pre-1977 vehicles, could benefit from this category of improper replacement.

<u>Use of High Sac Volume Injector</u>

The consistency of the responses, the fact that production was phased out in 1976 and a lack of motivation for substituting this part during rebuilding led to an arbitrary decision to set the low bound of occurrence at zero percent, the average at one percent and the high bound at 2 percent.

<u>Wrong Injection Spray Tip</u>

Again, the consistency of the responses and a lack of motivation for substituting this part during rebuilding led to an arbitrary decision to set the low bound of occurrence at zero percent, the average at one percent and the high bound at 2 percent.

<u>49 State Instead of California Camshaft</u>

Limited motivations were identified for this category of incorrect part replacement and these motivations applied only to older vehicles. Based on these observations and the consistent responses collected in the telephone survey a decision was made to set the lower bound frequency of occurrence at zero percent, the average at one percent and the high bound at 5 percent.

Incorrect Injection Timing

A substantial body of data was collected from ADS shops (Survey #2) and rebuild dealers (Survey #4) on the rate of occurrence for this category. Two separate questions in the survey addressed the frequency of observed modifications to injection timing. The first question, developed by Sierra, requested information on a range of fuel injection modifications, including whether engines were inspected for modifications, whether the throttle delay was disconnected, timing changes (both advance and retard) and changes in fuel rate. This question specifically addressed what the respondent saw in his shop. The second question, developed by Radian for a separate study, asked the respondent to report on his general knowledge of maintenance practices in the industry. Separate questions were asked for the perception of fuel injection timing advanced and retarded from manufacturer specifications for heavy duty, mid range and naturally aspirated engines. The response rate for each question was tabulated for ADS, dealer and fleet questionnaires separately. While the fleet data were not used in developing these scenarios, it was interesting to see that, as expected, the rate of occurrence of any injection modifications occurring within the respondent's shops was either noted as zero or left blank. The rate perceived to be occurring in the industry, however, was substantially higher, 17 percent advance and 11 percent retard for heavy duty engines. One comment attached to the retard response indicated rates as high as 60 percent; however, wear was noted as the primary cause.

The ADS survey respondents had a very poor response to the question of what they saw in their shops. Only 36 percent (17) of the 45 respondents inspected the injection equipment prior to overhaul, and of those 17 respondents, only 6 provided any information on injection timing questions. The data in these responses ranged from 0 to 40 percent for timing advance, with an average of 11 percent. The retard category indicated a range of 0 to 20 percent, with an average of 8 percent.

The same ADS survey showed a higher response rate, 42 percent, to the question of industry practices. While there were some variations between engine categories, the heavy duty response for timing advance ranged from 0 to 35 percent, with an average of 11 percent. The timing retard category ranged from 0 to 30 percent, with an average of 10 percent. Overall the in-shop and perceived rates of occurrence in the industry were quite consistent.

Telephone conversations with all of the ADS shops listed in California indicated a very low experience on perception of timing changes in California. The information collected in these responses indicated a lower level of timing changes, on the order of 5 percent, than identified in the 49 state ADS responses.

The average of all dealers surveyed, both in and out of state, also showed a consistent agreement between "in shop" and industry-perceived occurrence, with an average of 12 percent for the advance and 7 percent for the retard. On the other hand, using data from only those dealers that actually worked on injection equipment results in a higher perception of industry occurrence for the advance, averaging 15 percent, and a lower perceived rate for the retard, averaging 7 percent. California statistics for this category were in close agreement with the above data.

Following the guideline for showing the worst-case impact, the 15 percent average for advance was chosen and 5 percent for retard.

49 State Timing for California Certified Cummins Engines with Mechanically Variable Timing

No survey data were collected for this category. The mechanically variable timing (MVT) system used on California-certified Cummins engines was introduced in 1984. Conversations with dealers indicated numerous complaints about the performance of the engine and dissatisfaction expressed by drivers. The complaint is that the engine takes a long time to warm up from a cold start and that a considerable amount of smoking occurs during warm up. The smoking has brought CHP citations and requests that drivers not park the vehicles near their homes because of pressure from neighbors. While the concern about the smoking has stimulated driver interest in switching away from the MVT, there was near unanimous agreement that very few were willing to undertake the expense required to change the system. Accordingly, the rate of occurrence for all the scenarios was kept at 2 percent or less.

Incorrect Turbocharger

A substantial body of data was collected for incorrectly sized turbochargers. All of the data is based on the respondent's perception of what is occurring in the industry, not what his shop experience has been. The data indicated a very consistent response across all of the ADS and dealer categories of a 7-10 percent average incidence of "non-standard" type turbo's. Telephone conversations with California dealers and ADS members[1] confirmed that many drivers were "looking for more air" and better acceleration. Many of the shops indicated that more air led to less smoke and that less smoke meant more efficient combustion and lower pollution levels. Knowledge of pollutants other than smoke/particulate is almost non-existent. The ADS shop in the northern part of the state that serviced older vehicles indicated the use of non-standard turbo's was a very common method of increasing power and estimated a rate of occurrence as high

1. Numerous ADS shops also work with turbochargers and have relevant experience in this category.

as 60 percent. Overall, however, the responses and telephone surveys consistently showed an average value of about 10 percent.

Aftercooler Removed or Lack of Service

All questionnaires requested information on the percentage of heavy duty and mid-range trucks that had intercoolers with corrosion problems. The average response from all categories of respondents ranged from 3-6 percent. Conversations with dealers indicated that occasionally aftercoolers were removed from vehicles but this was usually to replace others that were broken or to increase the performance of another vehicle. The finding of corrosion problems on the order of 5 percent seemed reasonable to all respondents contacted with follow-up questions.

Dashpot or Throttle Delay Disconnect

As with the other fuel injection related questions, a large body of data was collected on this issue. It is based on shop experience; no data on industry practice was collected. The average rate of occurrence for this category was uniformly high across all of the respondent dealer categories and ranged from 25 to 41 percent, with individual estimates in several cases as high as 100 percent. The motivation for disconnecting the throttle delay is obviously to increase the acceleration of the vehicle, an improvement with universal appeal to drivers. Telephone conversations with shops confirmed the high rates. However, the ADS survey and conversations with California ADS members indicated a lower rate of occurrence on the order of 13-15 percent. Conversations with the ADS members also indicated that their estimates were based on perceptions of industry practice as they rarely work on the engines. Most of the ADS work occurs off site from the location of the engine work. The pumps and injectors are removed from the engine and sent to their shop for repair/overhaul. For this reason, their responses tended to be discounted; an average of 35 percent was selected for the base case.

Injection Pump Calibration

Data for this category were collected from all respondents on both their shop experience and their perception of industry practices. The responses uniformly indicated a high rate of modifications to injection pump pressure settings, with estimates ranging from 27 to 38 percent. Little difference was perceived between shop experience and industry practice. Non-California ADS members indicated a rate of about 27 percent in their experience, but provided almost no information on industry practice. Dealers on average indicated an experience of 29 percent. California dealers had an experience of 38 percent, but perceived the industry practice to be 24 percent.

All respondents indicated a substantial difference in the rate of modifications among heavy duty versus medium duty and naturally aspirated. The highest levels noted were for the heavy duty and the lowest for medium duty. Conversations with California ADS members and dealers confirmed the data collected in the survey. Many shops noted high sales of "buttons" that are used to alter pressure settings in injection pumps and felt the practice to be quite common. However, several indicated that the practice was more common in older vehicles as opposed to late model vehicles, where for certain manufacturers the modifications are more difficult. The northern California ADS member indicated that the practice was "much higher" on the older vehicles that he serviced. After reviewing the data and the telephone comments on the age incentive, a mean value of 30 percent was selected.

6.5 NET EMISSIONS IMPACT

The emission factor for all HDDV engines should be correctly represented as a "sawtooth" function, where emissions rise linearly with odometer until the first rebuild, drop back to initial (zero-mile) levels immediately after rebuild, increase again with odometer until the second rebuild, and so on. Incorrect rebuilds cause the emissions to be higher than the original zero-mile level after rebuild. In this context, incorrect rebuild can be viewed as resulting in an emission "offset", this term referring to a constant increment in emissions that is independent of odometer. The intercept term in the emission factor is defined as the zero-mile emission level. The degree of "offset" thus represents the difference in emissions improvements between properly and improperly rebuilt engines. A pictoral representation of these effects is provided in Fig. 6-1.

The percentage increases in emissions, summarized in Section 6.2, in combination with the rate of incorrect rebuild provides the net increase offset. In mathematical terms, the offset:

$$E_j = \sum_k I_j \times P_{jk} \times r_k$$

where I_j = the intercept of the emission factor for pollutant, j (HC, NOx, particulate)

P_{jk} = the percent increase in emissions of pollutant j for incorrect rebuild type, k

r_k = the observed rate of incorrect rebuild of component, k

and the summation is over all incorrectly rebuilt components of interest.

Calculations should ideally be performed for heavy-heavy and medium-heavy engines separately, because since 1980 all heavy-heavy engines have featured turbocharging and since 1984, aftercooling, while most medium-heavy engines do not have aftercooling, and one-third to one-half are still naturally aspirated. This means that there are fewer components that can be rebuilt incorrectly and hence, the estimate of increased emissions for heavy-heavy duty engines is larger than can be expected for medium-heavy engines.

Estimates of incremental HC and NOx emissions are shown in Tables 6-4 and 6-5 respectively for the base scenario as referred to in Table 6-3. These estimates represent the expected value of the emissions increment. The methodology used to compute the percentage emission increment takes the product of r_k and P_{jk} for each component subject to incorrect rebuild, and sums this product over all components to derive the total impact.

The mid-range estimate of the emission increment is 25 percent for HC and 3.3 percent for NOx. Using the same methodology, but substituting the high scenario values of r_k from Table 6-3 leads to an estimate of incremental impact of 45 percent for HC and 9.1 percent for NOx.

Table 6-6 provides a summary of the percentage increase in HC and NOx offsets for each of the scenarios considered. The range of impact for each of the pollutants is roughly tenfold. The size of the range reflects the diversity of information collected in the survey on the frequency at which improper rebuilds occur. The difference in the percentage offset impacts is due solely to the estimated frequency - the rate - of occurrence. The <u>percentage increase</u> in emissions for each category of improper rebuilding is constant for each pollutant acress the three scenarios. The product of the two values - the rate and the percentage increase - summed across all the categories of improper rebuilds leads to the estimated percentage in the emission's offset.

The corresponding changes in absolute emission values are obtained by multiplying these percentages by the appropriate emission factor intercepts given in Table 6-1 to obtain the emission "offsets" due to improper rebuilding. The values of the offset are shown in Table 6-7. The HC emission offset remains relatively constant at 0.2 g/BHP-hr, while the NOx offset decreases from 0.24 g/BHP-hr to 0.16 g/BHP-hr from MY1977-1979 to MY1984+ for the base scenario. We believe that the base scenario value is representative of the average fleet

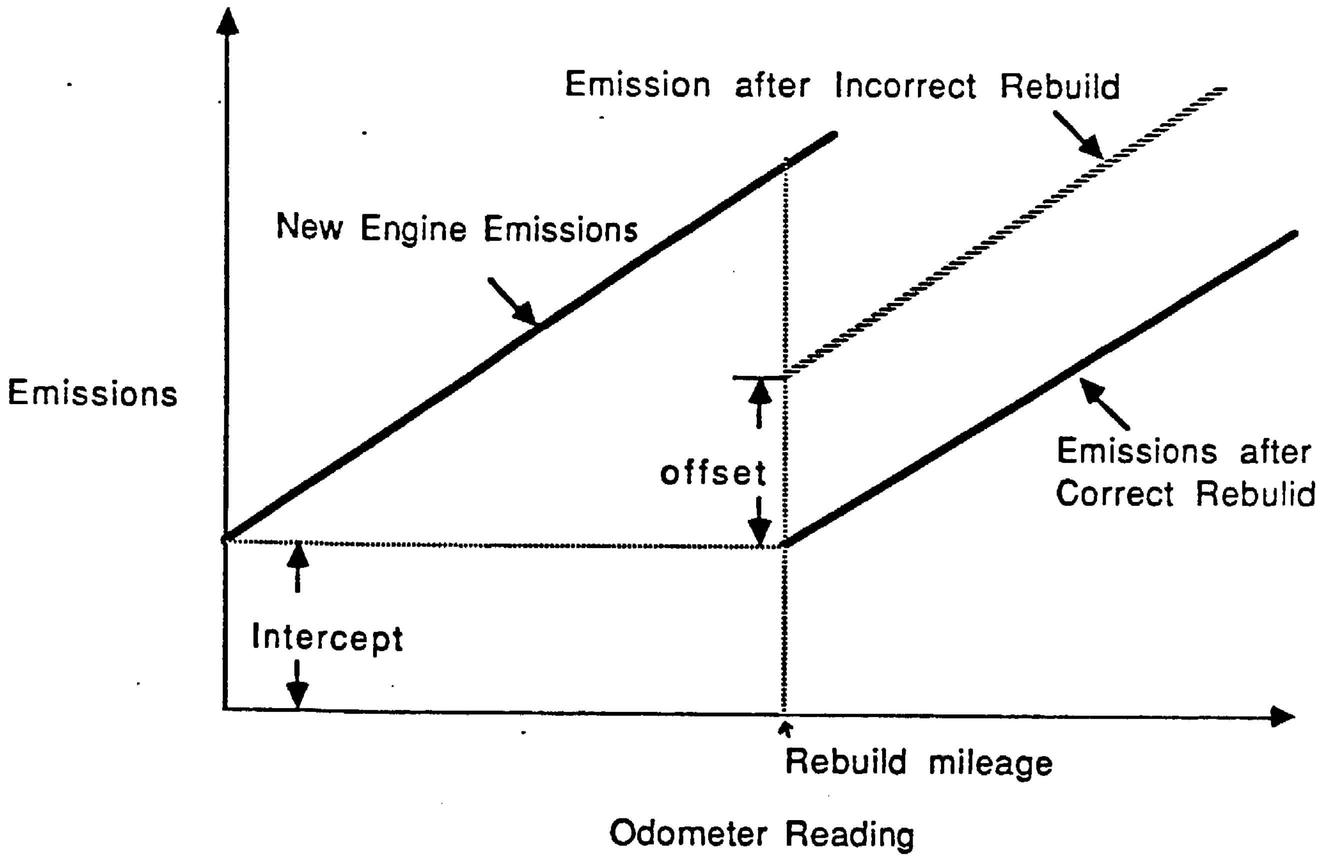

Figure 6-1
Illustration of Emissions Impact
of Correct and Incorrect Rebuild

emissions offset while the high scenario values may be representative for certain specific engine models in the fleet. Estimates for particulate emissions have not been provided as little information even on the particulate emission factors for new engines is available. No particulate standards have been in force for HDD engines for the entire period considered in this analysis. Engineering analysis[1,2] has shown that HC and particulate emissions are approximately correlated since they are both products of incomplete combustion of fuel; hence the percentage increases calculated for HC emissions should be approximately applicable to particulate emissions as well. If the intercept value of particulate emission factors is approximately 0.5 - 0.6 g/BHP-hr, then the "offset" for particulate emissions will be around 0.12 - 0.15 g/BHP-hr in the base scenario.

These estimates indicate that the emission offset due to rebuilding can be significant. However, closer examination of the individual contribution of each type of incorrect rebuild indicates:

- injection pump calibration and maladjustment of the smoke-puff limiter are responsible for 80 percent of excess HC emission; and
- advanced injection timing is responsible for over 67 percent of excess NOx emissions.

Note that all of the above items are <u>service</u> items and these maladjustments can occur during routine maintenance as well as rebuild. Excess emissions specifically related to <u>rebuild only</u> are very low, and range from less than 20 percent of the above estimate for HC to about 33% of the estimate for NOx.

A second factor not considered in this analysis is the positive contribution to emissions associated with rebuild. This occurs because engines are often uprated to a newer specification during

1. Automotive Particulate Emissions, K.G. Duleep, 2nd U.S. DOE Environmental Control Symposium, March 19, 1980.
2. N.H. Lipkea, John Johaston, Physical and Chemical Chemistry of Diesel Engines, SAE, SP430, 1978.

TABLE 6-4

PERCENTAGE HC EMISSIONS INCREASE FROM IMPROPER MAINTENANCE AND REBUILDING PROCEDURES HEAVY-HEAVY DUTY ENGINES

BASE SCENARIO

COMPONENT	p	r	r x p
INJECTION PUMP			
- 49-STATE INSTEAD OF CA	0.10	0.01	0.0010
- INCORRECT CALIBRATION	0.50	0.30	0.1500
INJECTOR			
- HIGH SAC VOLUME	1.50	0.01	0.0150
- WRONG SPRAY TIP	0.15	0.01	0.0015
TIMING			
- 49-STATE CAMSHAFT	0.15	0.01	0.0015
- ADVANCED	--	--	----
- RETARDED	0.15	0.05	0.0075
- MVT (CUMMINS)	0.15	0.01 (x0.55)*	0.0008
INCORRECT TURBOCHARGER	0.15	0.10	0.0150
AFTERCOOLER REMOVED/LACK OF SERVICE	0.10	0.05	0.0050
DISCONNECT DASHPOT THROTTLE DELAY	0.15	0.35	0.0525
TOTAL			0.2498

*Weighted for Cummins market penetration.

TABLE 6-5

PERCENTAGE NOx EMISSIONS INCREASE FROM IMPROPER MAINTENANCE AND REBUILDING PROCEDURES HEAVY-HEAVY DUTY ENGINES

BASE SCENARIO

COMPONENT	p	r	r x p
INJECTION PUMP			
- 49-STATE INSTEAD OF CA	0.10	0.01	0.0010
TIMING			
- 49-STATE CAMSHAFT	0.15	0.01	0.0015
- ADVANCED	0.15	0.15	0.0225
- MVT (CUMMINS)	0.15	0.01 (x0.55)*	0.0008
AFTERCOOLER REMOVAL	0.40	0.01	0.0040
LACK OF SERVICE	0.10	0.04	0.0040
TOTAL			0.0338

*Weighted for Cummins market penetration.

TABLE 6-6

SUMMARY OF THE EMISSIONS INCREASES
FROM THE SCENARIOS CONSIDERED

(% Increase)*

	HC	NOx
LOW	3.7	0.9
BASE	25.0	3.4
HIGH	44.7	9.1

* The percentage increase in the emissions offset.

TABLE 6-7

EMISSION OFFSETS DUE TO IMPROPER
MAINTENANCE AND REBUILDING PROCEDURES

(g/BHP-hr)

BASE SCENARIO

Model Year	HC	NOx
1977 - 1979	0.19	0.24
1980 - 1983	0.22	0.21
1984+	0.20	0.16

LOW SCENARIO

Model Year	HC	NOx
1977 - 1979	0.03	0.07
1980 - 1983	0.03	0.06
1984+	0.03	0.04

HIGH SCENARIO

Model Year	HC	NOx
1977 - 1979	0.34	0.65
1980 - 1983	0.39	0.55
1984+	0.36	0.44

rebuild, or newer low emission components are utilized instead of older components (such as high sac volume injectors). Although no information on this topic was collected, manufacturers suggest that between 10 and 20 percent of out-of-frame rebuilds may involve such uprating. Manufacturers also offer uprating kits that are specially certified for sale in California. Simple arithmetic indicates that at these levels of uprating, the emission benefits of rebuilding may be half as large as the total calculated emission increases due to incorrect rebuilding, and twice as large if the comparison were restricted to effects associated with rebuild only.

6.6 CALCULATION OF EMISSION IMPACTS IN TONS/DAY

The tons per day emission impacts due to improper rebuilds are calculated by converting g/BHP-hr to gms/mile and multiplying that volume times the VMT of each of the affected model years. To convert the estimated emission impacts to gms/mile, a conversion factor developed by EPA was used.[1] The equation is:

$$\text{gms/mile} = (\text{g/BHP-hr}) \times (\text{BHP-hr/mile})$$

The conversion factors vary by model year and represent the amount of work required to move a heavy-duty vehicle one mile. The conversion from gms/mile to tons/day is accomplished with the following formula:

$$\text{tons/day} = \frac{(\text{VMT}) \times (\text{gm/mile})}{(454\ \text{gm/lb})(2000\ \text{lb/ton})}$$

As shown in Table 6-7, the emissions effect due to improper rebuilds is dependent on the model year of the vehicle. Because the pre-1977 HDD engines were essentially uncontrolled, these engines were assumed

1. Review and Critique of Current Heavy-Duty Truck Emission Factors, Mobile Source Emissions Analysis for California, prepared for CARB by EEA and Sierra Research, June 1985.

not to be degraded through the rebuilding process. In order to account for the differential impacts of later model year vehicles, it is necessary to distribute the VMT across the model years in proportion to their share of registration and annual VMT. This was accomplished by obtaining an estimate of the total VMT associated with heavy-duty diesel vehicles and proportioning that travel to each group of model year vehicles operating in 1986.

Sierra obtained a copy of the 1986 BURDEN run and identified the total level of VMT estimated for "Heavy-Duty Diesel Trucks" across the entire state of California. That value was distributed across all model years in proportion to the distribution of registrations and annual travel levels contained in EMFAC7C for that category of vehicles. The resulting VMT by age estimate is shown in Table 6-8.

Also included in Table 6-8 is the Base Scenario gms/mile impact of the rebuilding process for both HC and NOx. Generally, the emissions impact of improper rebuilds increases with age, whereas the level of travel declines with age. The resulting tons/day impact depends on the relative change in the two values: for HC the greatest impact in tons/day is for late model vehicles; for NOx the impact is more evenly distributed across the model years.

The total HC and NOx tons/day values were then compared with the estimated tons/day emitted by heavy-duty diesel trucks and by the entire vehicle fleet in 1986[1]. The increase in HC emissions estimated for HDDV's is 15.6 percent; the increase for the vehicle fleet drops to less than 1 percent. For NOx, the increase in HDDV's is 2.4 percent, and for the fleet, less than 1 percent. These impacts are not insignificant; however, it must be remembered that these represent the cumulative effects of malmaintenance practices as well as rebuilding and remanufacturing impacts. The detailed information required to distinguish the respective impact of each category is unavailable.

1. BURDEN run for 1986 for the entire state of California.

Table 6-9 displays a similar set of information for the High Scenario estimate of emission impacts. This estimate incorporates all of the worst-case assumptions about the rate of occurrence of improper rebuilding procedures. The resulting increase in HDDV HC is 27.8 percent and 1.6 percent for the total vehicle fleet. The NOx impact is 6.3 percent for HDDV's, with a fleet impact of 2.0 percent.

Table 6-10 provides a summary of the HC and NOx impacts from the low scenario in 1986. It shows relatively low 2 and 3 tons per day increases for HC and NOx respectively. The percentage increases for total vehicle emissions in 1986 are very low, 0.1 percent for HC and 0.2 percent for NOx.

A comparison of the emission impacts generated from each of the scenarios is presented in Table 6-11. As discussed earlier in this chapter the range of emissions impacts is substantial; it is approximately tenfold. The range reflects the diversity of information collected in the survey on the <u>frequency at which improper rebuilds occur</u>. While the range of emission impacts is broad, the absolute impact is relatively small, 2 percent or less in all cases for both pollutants. Given the range of information sources and diversity of experience collected in the survey, it is not possible to construct an estimate of the error for the impacts reported in each of the scenarios. A sense of the error, however, can be gained through a comparison of the values reported in Table 6-11. The low and high bound values represent extreme estimates of the rate of occurrence in the field. The base values represent the best estimate of the rate of occurrence in the field.

The emission impacts reported in Table 6-11 include two categories of improper maladjustment:

-service or normal maintenance activities

-improper rebuilding procedures.

TABLE 6-8

CALCULATION OF TONS/DAY INCREASE
FROM IMPROPER MAINENANCE AND REBUILDING PROCEDURES
HEAVY DUTY DIESEL ENGINES
BASE SCENARIO

	VMT ($x10^3$)	HC (gm/mi)	Tons/Day[1]	NOx (gm/mi)	Tons/Day[1]
1986	1919.78	.52	1.10	.42	.89
1985	3002.92	.52	1.72	.42	1.39
1984	2616.59	.52	1.50	.42	1.21
1983	2408.02	.57	1.51	.55	1.46
1982	1934.00	.57	1.22	.55	1.17
1981	1896.08	.70	1.46	.67	1.40
1980	1417.32	.70	1.09	.67	1.05
1979	1339.11	.61	.90	.77	1.14
1978	1064.17	.61	.72	.77	.90
1977	957.52	.61	.64	.77	.81
TOTAL			11.62		11.42
% of total emitted by HDDV in 1986			15.6		2.4
% total vehicle emissions for 1986			0.9		0.7

1. Computed on a statewide basis.

TABLE 6-9

CALCULATION OF TONS/DAY INCREASE
FROM IMPROPER MAINTENANCE AND REBUILDING PROCEDURES
HEAVY DUTY DIESEL ENGINES
HIGH SCENARIO

	VMT ($x10^3$)	HC (gm/mi)	Tons/Day[1]	NOx (gm/mi)	Tons/Day[1]
1986	1919.78	.94	1.99	1.14	2.41
1985	3002.92	.94	3.11	1.14	3.77
1984	2616.59	.94	2.71	1.14	3.29
1983	2408.02	1.01	2.68	1.43	3.80
1982	1934.00	1.01	2.15	1.43	3.05
1981	1896.08	1.24	2.59	1.75	2.73
1980	1417.32	1.24	1.94	1.75	2.73
1979	1339.11	1.08	1.59	2.07	3.06
1978	1064.17	1.08	1.27	2.07	2.43
1977	957.52	1.08	1.14	2.07	2.19
TOTAL			21.17		30.39
% of total emitted by HDDV in 1986			27.8		6.3
% total vehicle emissions for 1986			1.6		2.0

1. Computed on a statewide basis.

TABLE 6-10

CALCULATION OF TONS/DAY INCREASE
FROM IMPROPER MAINTENANCE AND REBUILDING PROCEDURES
HEAVY DUTY DIESEL ENGINES
LOW SCENARIO

	VMT ($x10^3$)	HC (gm/mi)	Tons/Day[1]	NOx (gm/mi)	Tons/Day[1]
1986	1919.78	.08	.17	.10	.21
1985	3002.92	.08	.26	.10	.33
1984	2616.59	.08	.23	.10	.29
1983	2408.02	.10	.27	.16	.42
1982	1934.00	.10	.21	.16	.34
1981	1896.08	.10	.21	.19	.39
1980	1417.32	.10	.16	.19	.30
1979	1339.11	.10	.15	.22	.32
1978	1064.17	.10	.12	.22	.26
1977	957.52	.10	.11	.22	.23
TOTAL			1.89		3.09
% of total emitted by HDDV in 1986			2.5		0.6
% total vehicle emissions for 1986			0.1		0.2

1. Computed on a statewide basis.

TABLE 6-11

RANGE OF EMISSION IMPACTS
FROM IMPROPER MAINTENANCE AND REBUILDING
PROCEDURES IN 1986
(Statewide Basis; Tons/Day)

	HC	NOx
LOW	1.89	3.09
BASE	11.86	11.42
HIGH	21.17	30.39

Many of the improper rebuilding categories address equipment calibration. Improper calibration can occur in the course of normal maintenance procedures or during a rebuild. The information collected in the survey could not distinguish the source of the improper calibration observed on equipment coming into respondent shops. However, conversations with rebuild shops, manufacturers, and parts houses lead us to believe that warranty constraints limit the motivation for rebuild shops to violate manufacturer specfications. If this is true, then it is likely that the predominant source of improper equipment calibrations occurs in normal service activities.

An analysis of the contributions of the different improper rebuilding categories to the total emission impacts has indicated that the primary source of emission increases is related to improper equipment calibrations. That analysis showed that 80 percent of the emissions increase for HC and 67 percent of the increase for NOx in the base scenario is related to improper equipment calibration. Assuming that most of this activity is occurring outside of rebuilding activities, the emissions impacts presented in Table 6-11 can be reduced by more than 50 percent. The impact of improper rebuilding activities is then limited to 1 percent or less for both pollutants under the worst case estimates of activity.

APPENDIX A

COPIES OF QUESTIONNAIRES

APPENDIX A

COPIES OF QUESTIONNAIRES

Four separate questionnaires were employed in this study. These were sent to the following groups:

Survey #1	California rebuild and fuel injection repair facilities, to test respondent reactions to the information requested;
Survey #2	ADS members to collect infomation on fuel injection rebuild practices;
Survey #3	Truck fleets, large and small, to collect insights on fleet practices as distinct from rebuild facilities;
Survey #4	Rebuild facilities affiliated with independents and engine manufacturers to collect a broad range of California and non-California insights.

The rebuild facilities questionnaire was also distributed to the engine manufacturers for their comments and reactions.

The length of the surveys ranged from 8 to 10 pages. To minimize the length of this document only two questionnaires are included in this appendix: the first is the ADS; and the second is the rebuild facilities.

CALIFORNIA REBUILDING SURVEY

Name of Your Company: ______________________________

Address: ______________________________

City: ____________ State: ________ Zip: _____

Name of Person Completing Questionnaire: ____________________
(Please Print)

Telephone: ____________________

DEFINITIONS FOR USE IN THIS SURVEY:

"HEAVY-DUTY DIESEL ENGINE" - A Diesel engine used in a truck or bus with a gross vehicle weight (GVW) rating of more than 8,500 lbs.

"LINE-HAUL TRUCK DIESEL ENGINE" - A heavy-duty Diesel engine of the type used in a truck tractor-semitrailer combination. Typical examples would include the Cummins NTC-400, Detroit Diesel 8V-92TA, and Mack EM6-237.

"SHORT-HAUL TRUCK DIESEL ENGINE" - A Diesel engine of the type used in smaller local-haul or short-haul trucks, sometimes referred to as a "medium-duty" engine. Typical examples would include the Caterpillar 3208 or the International Harvester A210F.

"OVERHAUL" - Any type of rebuilding or reconditioning.

1. Which of the following best describes your company? (Check more than one box if necessary.)

- ☐ Diesel Engine **Sales and Service** (May Do Rebuilding)
- ☐ Diesel Engine **Service** (May Do Rebuilding)
- ☐ Engine **Rebuilding Only** (No Routine Service or Light Repair)
- ☐ Fuel Injection Equip. **Sales and Service** (May Do F.I. Rebuilds)
- ☐ Fuel Injection Equipment **Service** (May Do F.I. Rebuilding)
- ☐ Fuel Injection Equipment **Rebuilding Only** - No Routine Service

2. Does your company or any principal employees belong to any of the following organizations? Please check appropriate box or boxes.

   - □ Automotive Engine Rebuilders Association
   - □ Association of Diesel Specialists
   - □ Society of Automotive Engineers
   - □ Other Trade or Professional Organization ________________ (write in)

3. Does your company do any of its own overhauling of the following equipment types for heavy-duty Diesel truck or bus engines?

Pumps	Governors	Injectors	Turbochargers
□ Yes	□ Yes	□ Yes	□ Yes
□ No	□ No	□ No	□ No

   If you answered "Yes" to any of the above, do you use aftermarket parts or Original Equipment Manufacturer parts during the overhauling of that equipment?

   - □ Use Mostly Aftermarket Parts
   - □ Use Only Aftermarket Parts
   - □ Use Mostly OEM Parts
   - □ Use Only OEM Parts
   - □ Use a Mix of OEM and Aftermarket Parts

4. What makes of injection equipment do you overhaul? Please check appropriate box or boxes.

   - □ Cummins
   - □ Caterpillar
   - □ Detroit Diesel (GM)
   - □ Mack
   - □ International Harvester
   - □ Perkins
   - □ ADECO
   - □ Robert Bosh
   - □ Lucas
   - □ Nippondenso
   - □ Stanadyne
   - □ United Technologies
   - □ Yanmar

5. When you receive equipment for overhauling, do you usually know how many total miles have been put on the equipment since it was new or last serviced?

Equipment Type	Yes	No	Average Miles Before 1st Overhaul	Average Miles Between 1st & 2nd Overhaul
Injector Pumps	□	□	____________	____________
Injectors	□	□	____________	____________
Turbochargers	□	□	____________	____________
Governors	□	□	____________	____________

12. When you overhaul any of the following equipment types do you affix some type of label indicating that your Company overhauled it?

Equipment Type	Yes	No
Injection Pumps	☐	☐
Injectors	☐	☐
Turbochargers	☐	☐
Governors	☐	☐

7. What is the average cost to overhaul the following components?

Injection Pumps = $ ________

Injectors = $ ________

Turbochargers = $ ________

Governors = $ ________

8. Do you determine whether the fuel injection system has been modified before you overhaul it?

☐ Yes ☐ No

If yes, Percent with Modified Fuel Injection Systems = __ %

Dashpot, Automatic Fuel Control, or
Throttle Delay Disconnected or Improperly Adjusted = ___ %
Injection Timing Too Advanced = ___ %
Injection Timing Too Retarded = ___ %
Fuel Rate Increased From Manufacturers Specifications = ___ %

9. Do you rebuild fuel injection equipment in the same way regardless of whether the equipment is for an engine originally sold in the state of California or some other state?

☐ Yes ☐ No

If your answer was "No", what is different about the way you rebuild fuel injection equipment for engines originally sold in California? (please describe briefly)

10. Do you have difficulty obtaining new (from the OEM) replacement parts for fuel injection systems used on California certified engines?

☐ Yes ☐ No

Do you have difficulty obtaining aftermarket replacement parts for fuel injection systems used on California certified engines?

☐ Yes ☐ No

11. Do you feel that there is a difference between the quality of new replacement parts (from the OEM) and aftermarket parts available for the following equipment types?

Equipment Types	Yes	No
Injection Pumps	☐	☐
Injectors	☐	☐
Turbochargers	☐	☐
Governors	☐	☐

12. Does your company perform bench tests or flow tests on fuel injection equipment used in the overhauling of Diesel engines?

☐ Yes ☐ No

If yes, do you compare test results with specifications supplied by the Original Equipment Manufacturer of the fuel injection equipment, or do you use your own specifications?

☐ Use OEM Specifications ☐ Use Own Specifications

13. Are there any regulations that you are aware of that prohibit you from modifying equipment when it is being overhauled?

☐ Yes ☐ No

If yes, please write in the name of the agency that enforces the regulations: ______________________

14. Do you warranty the service that you provide? ☐ Yes ☐ No

If yes, please identify the warranty period.

Equipment Type	Miles	Years
Injection Pumps	______	____
Injectors	______	____
Turbochargers	______	____
Governors	______	____

As a person familiar with trucks and maintenance practices, you probably have a good idea of how common different kinds of problems are in the industry. The following are some problems that can cause increased smoke and pollutant emissions from diesel engines. Please tell us how common you think each kind of problem is by writing in the space provided your best estimate of the percentage of trucks on the road that you think have this problem. If you have no idea how common a problem is, please leave the space blank.

There are spaces for three answers for each question, one for line-haul trucks (trucks used for hauling freight between cities), one for all other types of trucks with turbocharged engines, and one for trucks with naturally aspirated (non-turbocharged) engines. Please answer the questions separately for each type of truck.

15. Smoking due to maximum fuel level set higher than manufactuer's spec (or larger-than-standard injectors used on Detroit Diesel Engines).

Percent of trucks with problem

Line Haul _____ Other Turbocharged _____ Naturally Aspirated _____

16. Fuel injection timing advanced from manufacturer's spec to increase power or fuel economy.

Percent of trucks with problem

Line Haul _____ Other Turbocharged _____ Naturally Aspirated _____

17. Fuel injection timing retarded from manufacturer's spec (resulting in excess smoke).

Percent of trucks with problem

Line Haul _____ Other Turbocharged _____ Naturally Aspirated _____

18. Air filter (or blower inlect screen) dirty or clogged enough to cause excess smoke.

Percent of trucks with problem

Line Haul _____ Other Turbocharged _____ Naturally Aspirated _____

19. Pressure leaks in the inlet air or exhaust piping, causing loss of boost and excessive smoke.

Percent of trucks with problem

Line Haul _____ Other Turbocharged _____

20. Intercooler clogged or corroded, causing loss of boost and excessive smoke (please answer this question for the percentage of trucks with intercoolers having this problem).

Percent of trucks with problem

Line Haul _____ Other Turbocharged _____

21. Turbocharger worn or defective, causing loss of boost and excessive smoke.

Percent of trucks with problem

Line Haul _____ Other Turbocharged _____

22. Turbocharger replaced with a non-standard type.

Percent of trucks with problem

Line Haul _____ Other Turbocharged _____

23. "Smoke limiter" -- anaeroid or throttle delay -- disconnected, resulting in excess smoke.

Percent of trucks with problem

Line Haul _____ Other Turbocharged _____

24. "Smoke limiter" reset to allow faster acceleration, resulting in excess smoke.

Percent of trucks with problem

Line Haul _____ Other Turbocharged _____

25. Fuel injectors worn or clogged enough to cause excess smoke.

Percent of trucks with problem

Line Haul _____ Other Turbocharged _____ Naturally Aspirated _____

26. Excessive backpressure due to exhaust system deterioration or alterations, resulting in excessive smoke.

Percent of trucks with problem

Line Haul _____ Other Turbocharged _____ Naturally Aspirated _____

Are there any other maintenance or tampering-related problems that you know of that could cause excess emissions in heavy duty Diesel engines? Please list them below. Please tell us how common you think these problems are.

____

____

Do you have any other comments or information about this subject that you would like to add?

Thank you for answering the questions. Please mail the completed questionnaire back to Sierra Research in the envelope provided.

SURVEY OF HEAVY-DUTY ENGINE REBUILDING PRACTICES CONDUCTED FOR THE STATE OF CALIFORNIA

Name of Your Company: ____________________

Address: ____________________

City: __________ State: __________ Zip: ______

Name of Person Completing Questionnaire: ____________________
(Please Print)

Title: ____________________

Telephone: ____________________

The purpose of this survey is to collect information on your rebuilding experience (both in-house and with vendors) on mid-range and heavy-duty diesel engines. Do not consult your records just answer the questions on the basis of your experience. Thanks for your help!

1. Does your company or any principal employees belong to any of the following organizations? Please check appropriate box or boxes.

   - ☐ Automotive Engine Rebuilders Association
   - ☐ Association of Diesel Specialists
   - ☐ Society of Automotive Engineers
   - ☐ Other Trade or Professional Organization ____________________
     (write in)

2. Does your company overhaul heavy-duty Diesel truck or bus engines?

   ☐ Yes ☐ No

If the answer to question number 2 was "Yes", please answer the following questions. If the answer was "No", please skip to question number 20 on page 7.

3. Approximately how many heavy-duty Diesel truck or bus engines has your company overhauled during the last twelve months?

Number of In-Frame Rebuilds during last 12 months

In House ____________

By Vendor ____________

Number of Out-of-Frame Rebuilds in last 12 months

In House ____________

By Vendor ____________

4. Please identify the types of engines that you overhaul.

HEAVY-DUTY

- ☐ Cummins
- ☐ Caterpillar
- ☐ Detroit Diesel (GM)
- ☐ Mack
- ☐ International Harvester
- ☐ Other ______________________________ (write in)

MEDIUM-DUTY

- ☐ Cummins
- ☐ Caterpillar
- ☐ Detroit Diesel (GM)
- ☐ Mack
- ☐ International Harvester
- ☐ Other ______________________________ (write in)

5. Do you usually know whether the engine has ever been overhauled before?

	Yes	No
In-House	☐	☐
By-Vendor	☐	☐
Miles Since Last Rebuild	☐	☐

6. Based on your experience and general knowledge, what is the typical mileage accumulated on an engine before it receives its first overhaul and between its first and second overhaul?

	Average Miles Before 1st Overhaul	Average Miles Between 1st & 2nd Overhaul
Line-haul truck engines =	__________	__________
Short-haul truck engines =	__________	__________
Bus engines =	__________	__________

7. What type of reconditioning is usually done the second time a heavy-duty Diesel engine is overhauled?

Short-Haul Engines	Line-Haul Engines	Bus Engines
☐ In-Frame Rebuild	☐ In-Frame Rebuild	☐ In-Frame Rebuild
☐ Out-of-Frame "	☐ Out-of-Frame "	☐ Out-of-Frame "
☐ Remanufacturing	☐ Remanufacturing	☐ Remanufacturing

8. What percentage of the Diesel engines that you overhaul come from trucks or buses that have had a failure?

_____ %

9. Do you use an on-going oil analysis program?

☐ Yes ☐ No

10 What percentage of engines have the following major cores rejected?

Blocks	________
Cranks	________
Cylinder Heads	________
Camshafts	________

11. What is the average cost (less major core value) for a rebuild of a Line-Haul Diesel truck engine?

	Heavy-Duty	Medium-Duty
In-Frame Rebuild Cost = $	________	________
Out-of-Frame Rebuild Cost = $	________	________

12. During "In-Frame Rebuilds", which of the following components are usually serviced and how are they serviced?

	Not Serviced	Original Part Rebuilt	Replaced With Rebuilt Parts	Replaced With New OEM Parts	Replaced With New Aftermarket Parts
Piston Rings:	☐	☐	☐	☐	☐
Cylinder Liners:	☐	☐	☐	☐	☐
Pistons:	☐	☐	☐	☐	☐
Cylinder Heads	☐	☐	☐	☐	☐
Fuel Injectors:	☐	☐	☐	☐	☐
Injection Pumps:	☐	☐	☐	☐	☐
Governors or Fuel Delay Mechanisms:	☐	☐	☐	☐	☐
Turbochargers:	☐	☐	☐	☐	☐
Aftercoolers:	☐	☐	☐	☐	☐
Roots Blowers:	☐	☐	☐	☐	☐
Rocker Arms:	☐	☐	☐	☐	☐

13. During "Out-of-Frame Rebuilds", which of the following components are usually serviced and how are they serviced?

	Not Serviced	Original Part Rebuilt	Replaced With Rebuilt Parts	Replaced With New OEM Parts	Replaced With New Aftermarket Parts
Piston Rings:	☐	☐	☐	☐	☐
Cylinder Liners:	☐	☐	☐	☐	☐
Pistons:	☐	☐	☐	☐	☐
Cylinder Heads	☐	☐	☐	☐	☐
Fuel Injectors:	☐	☐	☐	☐	☐
Injection Pumps:	☐	☐	☐	☐	☐
Governors or Fuel					

Delay Mechanisms:	☐	☐	☐	☐	☐
Turbochargers:	☐	☐	☐	☐	☐
Aftercoolers:	☐	☐	☐	☐	☐
Roots Blowers:	☐	☐	☐	☐	☐
Rocker Arms:	☐	☐	☐	☐	☐

14. When you overhaul a Diesel engine, do you determine whether the engine was originally certified to meet California emission standards?

☐ Yes ☐ No

Is a tear down analysis performed?

☐ Yes ☐ No

15. Do you ever overhaul engines that require special replacement parts because they were originally sold in the state of California?

☐ Yes ☐ No

If yes, what parts are usually different?

____

____

____

Also, if the answer was "Yes", do you usually use California-specification replacement parts?

☐ Yes ☐ No

If you don't always use California specification replacement parts, why not?

☐ Hard to Find
☐ Expensive to Inventory
☐ Too Expensive
☐ Worse Fuel Economy
☐ Worse Performance
☐ Other (Explain)_______

____

____

16. Do you use instruments to measure smoke or gaseous emissions on engines at the completion of an overhaul?

Smoke	Hydrocarbons	Carbon Monoxide	Oxides of Nitrogen
□ Yes	□ Yes	□ Yes	□ Yes
□ No	□ No	□ No	□ No

17. Do you conduct any power or fuel consumption measurements on engines at the completion of an overhaul?

Full Power Curve	Check Power or Torque at Certain Points	Measure Fuel Consumption
□ Yes	□ Yes	□ Yes
□ No	□ No	□ No

18 What type of air cleaner inspection/maintenance program do you have? Please check the categories that best describe your program.

______ restriction guage

______ mileage

______ preventative maintenance

______ driver write-up

______ excess smoke

______ other (please specify)

____

____

____

19. Are any of the Diesel engines you overhaul ever "upgraded" or "uprated" during the overhaul process? For example, do you ever increase the horsepower or torque rating of an engine from its original specifications?

□ Yes, Upgrading or Uprating is sometimes performed
If Yes, the percentage of engines Upgraded/Uprated = __ %
□ No, Upgrading or Uprating is never performed

20. Do you determine whether the fuel injection system has been modified before you overhaul a Diesel engine? If so, what percentage of the Diesel engines that you overhaul appear to have modified fuel injection systems (for example, increased fuel rate)?

Engines Inspected for Modifications? □ Yes □ No

If yes, Percent with Modified Fuel Injection Systems = __ %

Dashpot, Automatic Fuel Control, or Throttle Delay Disconnected or Improperly Adjusted = ___ %
Injection Timing Too Advanced = ___ %
Injection Timing Too Retarded = ___ %
Fuel Rate Increased From Manufacturers Specifications = ___ %

21. Does your company do any of its own overhauling of fuel injection equipment for Diesel truck or bus engines?

Pumps	Governors	Injectors
□ Yes	□ Yes	□ Yes
□ No	□ No	□ No

If you answered "Yes" to any of the above, do you use aftermarket parts or Original Equipment Manufacturer parts during the overhauling of fuel injection equipment?

□ Use Mostly Aftermarket Parts
□ Use Only Aftermarket Parts
□ Use Mostly OEM Parts
□ Use Only OEM Parts
□ Use a Mix of OEM and Aftermarket Parts

Do you rebuild fuel injection equipment in the same way regardless of whether the equipment is for an engine originally sold in the state of California or some other state?

□ Yes □ No

If your answer was "No", what is different about the way you rebuild fuel injection equipment for engines originally sold in California? (please describe briefly)

____

____

____

____

22. Does your company perform bench tests or flow tests on fuel injection equipment used in the overhauling of Diesel engines?

□ Yes □ No

If yes, do you compare test results with specifications supplied by the Original Equipment Manufacturer of the fuel injection equipment, or do you use your own specifications?

□ Use OEM Specifications □ Use Own Specifications

23. Are there any regulations that you are aware of that prohibit you from modifying engines when they are being overhauled?

□ Yes □ No

If yes, please write in the name of the agency that enforces the regulations: ______________________________

As a person familiar with trucks and maintenance practices, you probably have a good idea of how common different kinds of problems are in the industry. The following are some problems that can cause increased smoke and pollutant emissions from diesel engines. Please tell us how common you think each kind of problem is by writing in the space provided your best estimate of the <u>percentage</u> of trucks on the road that you think have this problem. If you have no idea how common a problem is, please leave the space blank.

There are spaces for three answers for each question, one for heavy duty trucks, one for mid-range trucks, and one for trucks with naturally aspirated (non-turbocharged) engines. Please answer the questions separately for each type of truck.

24. Smoking due to maximum fuel level set higher than manufactuer's spec (or larger-than-standard injectors used on Detroit Diesel Engines).

Percent of trucks with problem

Heavy Duty _____ Mid-Range _____ Naturally Aspirated _____

25 Fuel injection timing advanced from manufacturer's spec to increase power or fuel economy.

Percent of trucks with problem

Heavy Duty _____ Mid-Range _____ Naturally Aspirated _____

26. Fuel injection timing retarded from manufacturer's spec (resulting in excess smoke).

Percent of trucks with problem

Heavy Duty _____ Mid-Range _____ Naturally Aspirated _____

27. Air filter (or blower inlect screen) dirty or clogged enough to cause excess smoke.

Percent of trucks with problem

Heavy Duty _____ Mid-Range _____ Naturally Aspirated _____

27. Pressure leaks in the inlet air or exhaust piping, causing loss of boost and excessive smoke.

Percent of trucks with problem

Heavy Duty _____ Mid-Range _____

28. Intercooler clogged or corroded, causing loss of boost and excessive smoke (please answer this question for the percentage of trucks with intercoolers having this problem).

Percent of trucks with problem

Heavy Duty _____ Mid-Range _____

29. Turbocharger worn or defective, causing loss of boost and excessive smoke.

Percent of trucks with problem

Heavy Duty _____ Mid-Range _____

30. Turbocharger replaced with a non-standard type.

Percent of trucks with problem

Heavy Duty _____ Mid-Range _____

31. "Smoke limiter" -- anaeroid or throttle delay -- disconnected, resulting in excess smoke.

Percent of trucks with problem

Heavy Duty _____ Mid-Range _____

32. "Smoke limiter" reset to allow faster acceleration, resulting in excess smoke.

Percent of trucks with problem

Heavy Duty _____ Mid-Range _____

33. Fuel injectors worn or clogged enough to cause excess smoke.

Percent of trucks with problem

Heavy Duty _____ Mid-Range _____ Naturally Aspirated _____

Are there any other maintenance or tampering-related problems that you know of that could cause excess emissions in heavy duty Diesel engines? Please list them below. Please tell us how common you think these problems are.

____

____

Do you have any other comments or information about this subject that you would like to add?

____

____

____

Thank you for answering the questions. Please mail the completed questionnaire back in the envelope provided.

APPENDIX B

PART NUMBERS FOR EMISSIONS CRITICAL PARTS

PART NOS. FOR EMISSION RELATED COMPONENTS
CUMMINS

	Federal		California
Cummins NTC 400/NTCC400	CPL0267	CPL0454	
Injectors	3018346	3009466	3022269
	3007510	3018339	
	3006503	3018344	
Pistons	3008472	3010570	216020
			3007245
Camshafts	3000850	3022365	3021589
	3006777	3020914	3025517
	3021588	3025518	3019124
Variable Timing	N/A		3024745
			3021043
Turbocharger	AR45428	3032067	3011902
	3025391	3032068	3025467
	3021885	3032080	3025814
	3024741		

PART NOS. FOR EMISSION RELATED COMPONENTS
INTERNATIONAL HARVESTER

	Federal	California
DT466 A210F/DTI466 A210C		
Pump	689644C92	691346C91
	689645C92	691347C91
Nozzle	688840C91	688840C91 (identical)
Turbo	684596C91	
	684698C91	684698C91
	684937C91	
Intercooler	N/A	686210C91
DT466 A180F/A180C		
Pump	689646C91	691344C91
	689647C91	691345C91
Nozzle	688840C91	691348C91
Turbo	As for 210F	691409C91

PART NOS. FOR EMISSION RELATED COMPONENTS
DETROIT DIESEL ALLISON

	Federal	California
DDA 8.2 NA		
Injectors	5229850	5226175
DDA 8.2 Turbo		
Injectors	5229915	5226180
6V-92 T		
Injector	5229810	5226090
Blower	8923953	8922495
	5101528	
Turbocharger (from 9/81)	8924252	8923051

PART NOS. FOR EMISSION RELATED COMPONENTS
CATERPILLAR

	Federal	California
CAT3208 (low emissions)		
Fuel injection pump	9W5779	7W5476
	7W2840	1W6741
EGR	N/A	9N2404/9N3121
		9N2300/1W6124
Camshaft drive gear	9N3873	9N3874
CAT 3208 T		
Fuel injection pump	9N5778	1W6740
Turbocharger	9N6568	1W6718
	2W2589	2W2589
	4W1134	4W1135
Piston	1W5793	1W2063
CAT 3406 DITA		
Fuel injection pump	1W5079	9N6102
Nozzle	9N3246	9L6884
Turbocharger	9N5264	9N2703
Injection timing	28°	18.5°

APPENDIX C

SUMMARY OF SITE VISITS

APPENDIX C

SUMMARY OF SITE VISITS

The site surveys were conducted to collect the following information:

- clarification of data collected in the survey responses;
- the sophistication of smaller facilities in conducting rebuilding operations;
- attitudes towards emission control system maintenance;
- use of internal versus external personnel to perform specialized repair tasks;
- attitudes towards the quality of aftermarket parts;
- vehicle service life and rebuild costs.

The site visits were conducted after most of the survey data had been collected. This afforded the opportunity to resolve questions that we developed after a preliminary analysis of the data. The insights provided by these visits helped us to better understand the data collected as well as frame questions to suppliers and rebuild shops in follow-up telephone conversations. Most of the people interviewed wanted their identities kept confidential, therefore none of the companies, their locations, or the people providing the information will be identified in this report.

Most of the site visits were conducted at facilities that had responded to survey. This approach minimized the effort needed to identify locations willing to allow an inspection and aided the interpretation of their questionnaire responses. The first visit was targeted for a smaller facility that conducted less than 50 in-frame rebuilds per year. The survey data collected from the fleets contained inconsistent data on the frequency of repair and the cost of repair at low volume facilities. At that time we were concerned that these operations might be motivated to use lower cost parts of inferior quality to conserve maintenance expenses.

The first shop visited was quite sophisticated in the procedures used to track maintenance activities. Computerized records are maintained on the results of maintenance activities conducted on every vehicle owned. A preventative maintenance inspection was performed every 90 days regardless of the vehicle's use. The name of the mechanic performing the repairs is also tracked. Similar statistics are also kept on the results of all rebuilds conducted.

The preventative maintenance inspections checked the condition of approximately 60 components. Categories of components checked included:

- brakes
- electrical equipment
- miscellaneous equipment
- chassis
- engine

Separate data were collected on the condition of the air intake system. The focus of these inspections was not on emissions control equipment, although the California Highway Patrol does perform regular checks on the level of visible smoke emitted. These checks are conducted frequently enough to cause the regular inspection of smoke puff limiters. No checks on the settings of the fuel injection system are conducted in these inspections.

The surprising feature of this visit was that little work was conducted in-house on the out-of-frame rebuilds. The volume of out-of-frames conducted was insufficient to support either the work force or the equipment necessary to do the work internally. Therefore, after the engine was removed from the vehicle it was torn down and component parts and subassemblies were sent to specialists for repair. This finding is not surprising for fuel injection equipment, but it is for oil pumps, valves, camshafts, etc. In effect the smaller shops were found to act as general contractors for the inspection, repair and replacement of all equipment. Their primary function was to assemble and disassemble the engine.

Shop policies on the use of aftermarket parts varied. Some maintain a strict policy of using only OEM new or rebuilt parts. Others were more flexible about the use of aftermarket parts, "if the quality of the parts is good and their prices are better we use them". One of the firms had a policy of using only OEM parts in all rebuilds except the one performed right before the vehicle was to be sold. In that last rebuild, aftermarket parts were used.

One rebuild shop allowed us to actually look at the part numbers used in a rebuild. This was not an easy request to make, but it allowed us to independently assess whether California spec parts were in fact being used in that particular repair. By comparing the part numbers with those contained in Appendix B we were able to confirm that the correct parts were being employed.

The fleets visited indicated that they maintained careful controls on the fuel rates used in their engines. It became clear from conversations with them and with rebuild shops that drivers frequently want to see the fuel rates "turned-up". The fleets, in general, view this practice as expensive because of the increased fuel cost. They are also concerned about the effects on engine durability. While owner operators were not directly involved in this study it is apparent that this group is in the best position to implement fuel injection system modifications. Many of the fleets maintain seals on the fuel injection pump housings to insure that tampering does not occur. Rebuild shops indicated that they frequently turned down these requests because of the warranty problems that result.

APPENDIX D

LIST OF ABBREVIATIONS/GLOSSARY

APPENDIX D

LIST OF ABBREVIATIONS/GLOSSARY

ADS	Association of Diesel Specialists
AERA	Automotive Engine Rebuilders Association
AMP's	Aftermarket Parts
ARB	Air Resources Board
CO	Carbon Monoxide
DDA	GM/Detroit Diesel Allison
EGR	Exhaust Gas Recirculation
EPA	Environmental Protection Agency
g/BHP-hr	Grams/Brake-horsepower-hour
GVW	Gross Vehicle Weight
HC	Hydrocarbon
HDDE	Heavy Duty Diesel Engine
HDDV	Heavy Duty Diesel Vehicle
HFID	Heated Flame Ionization Detector
IH	International Harvester
I/M	Inspection and Maintenance
MIKE	The application of a micrometer to measure the dimensions of surfaces that experience wear to determine if they are within tolerances specified by the factory.
MVT	Mechanically Variable Timing
NOx	Oxides of Nitrogen
OEM	Original Equipment Manufacturer
PIE	Pacific Intermountain Express